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ANALYSIS, DIAGNOSIS, AND REDESIGN OF AN INDEXING TABLE INCORPORATED IN A CAMSHAFT PRODUCTION LINE.

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NOTE: The keywords and sentences of the following paragraphs of this project are highlighted in bold type to reach a more straightforward reading. By reading these keywords, the reader will rapidly understand the fundamental idea of each paragraph.

Part 1

1 Descriptive memory

In this section, we will identify the **aim of this project**, its context, and the reasons why the **implementation of the adopted solutions** is going to represent an **improvement in economic, performance, and timing areas**.

In this first part, we will also expose the **problems** that we had to deal with when developing this project, the **different solutions** that could have been taken to reach our goal, explaining why the alternative that we chose was the most suitable and why it has been considered as the **optimum**. We will explain in detail the chosen solution by describing step by step each decision that we made. Also, every assumption is going to be followed with its back up in order to clarify every possible explanation. Moreover, we will also evaluate the **impacts of the project and its reliability itself**.

At the end of this section, we will check the obtained results of the implemented actions to discern the accomplishment of the main goals of the project.

Descriptive memory Index

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NOTE: All figures in this project are compiled by the author. Tables that are extracted from external sources are referenced following the APA style.

1.1. Aims of the project

This project aims to carry out the **breakdown analysis, reparation, and design improvement** of the indexing table from Fibro. This component is placed in Etxe-tar's machining center of the 12th operation of the camshaft production line, in the Valencia Engine Plant (VEP) from Ford.

The goal of the **root-cause analysis of the problem** is to discern if the breakdown occurred due to poor design, a not desirable application of the machinery, or failure caused by a specific action, an impact that would initiate the wear, for example. Moreover, despite the short working time of the table, it would be interesting to study if its components arrived at the end of their useful life. Then, we could determine if the table was supposed to suffer a breakdown at this time according to design calculations.

The other objective of this project is to perform the **repairs of the indexing table and introduce an improvement in the design** to increase the mechanism's reliability. These actions imply taking into account every possible solution considering both economic and technical factors. We must also keep in mind the capacity and machinery limitations at the central predictive and pre-emptive maintenance workshop of the VEP to carry out reparations.

In conclusion, the global aim of this project is to **increase the reliability and maintainability** of the indexing table while reaching significant independence from the manufacturer, in this case, Fibro. The embedded consequence of this greater independence is the capability of performing future reparations by Ford, and the performance increase in Etxe-tar's machining centers. Not just in Ford but also globally, making its products more profitable for its clients.

1.2. Introduction to the problem: Background, motivation, and justification

1.2.1. Background

1.2.1.1. Etxe-tar and Ford

Etxe-tar is part of Inzu Group; this is an internationally recognized industrial group formed by highly specialized companies from different sectors, these are: machinery for advanced manufacturing systems (Etxe-tar's activity), digital, circular economy, tile industry, and R&D, that is a total of 5 different sectors, with 11 companies involved.

The group, located in northern Spain, exports more than 90% of its turnover with the support of a global sales and service network.

Etxe-tar is a vital asset for this group, founded in 1957 in the Basque country with more than 60 years of experience; it supplies engineering solutions to its clients, enhancing their productivity. The company, as well as the Inzu group, has a global impact, with a **presence in over 20 countries** and service centers in Mexico, USA, England, Germany, India, China, and Russia. Its headquarters are located in Elgoibar, Basque country. **It exports 90% of its turnover** thanks to three production plants and a network of strategic suppliers. Its products and services are diverse. Among them, we can find: machining centers, turnkey lines, special purpose machines, and journal milling and turning solutions. The totality of Etxe-tar's machinery specializes in car manufacturing. The company has been **awarded several times by its clients** including Volkswagen Award 2005 in the category of "entrepreneurial performance," Ford investment efficiency award in 2014-2015, General Motors supplier of the year award in 2015, Volvo Cars quality excellence award in 2017 and Chery Jaguar Land Rover excellent supplier award in 2018 [1]. As we can see, Etxe-tar is a Spanish company with a high international impact with a bright future ahead, as the received recognition and expansion show.

On the other hand, **Ford motor company** is an American global company employing 190.000 [2] workers worldwide with its headquarters placed in Dearborn, Michigan. It was founded in 1903 by Henry Ford, the creator of the "production lines" as we know them today, enabling higher production volumes and decreasing the price of vehicles enormously. Nowadays, this system is used in many different sectors due to its excellent efficiency, as we all now.

Today, Ford is the **5th biggest car manufacturer** after Toyota, Volkswagen, Hyundai, and General Motors. As opposed to its competitors, Ford Motor Company **focus its production on just its brand**, as the company decided to sell Jaguar, Land Rover, and Volvo during the big financial crisis in 2008 to avoid bankruptcy.

Recently **Ford and Volkswagen** announced a **collaboration** to produce and design small commercial vehicles as well as mid-size pick-ups. Moreover, they also decided to collaborate to develop future electric cars and autonomous vehicles for both companies. This alliance will help both manufacturers to adapt to a new era of hybrid and electric cars and keep its enviable position in terms of productivity.

Ford factory in Valencia is responsible for the assembly and manufacturing of diverse models of the brand. Its engine plant is one of the most efficient in the automotive industry, producing three different engines: 2.0 L4-cyl Duratec HE, 2.3 L4-Cyl. Duratec HE and 2.0 L4- cyl. EcoBoost exporting much of its production to the USA [2].

1.2.1.2. Indexing tables general description

Indexing tables were used, at their beginnings as the responsible of the manual angular positioning in milling processes. However, nowadays, indexing tables are a commonly used **solution in machining centers (CNC)**. These components add a rotary movement to the typical vertical and horizontal displacement in a CNC. The difference is that these two translations are made by the machining tool, while the rotary movement is made by the machined part that is placed on the indexing table. Usually, the part can rotate over one or two axes, depending on the process that it is going through. These movements enable milling or drilling on different surfaces of the machined component.

The precision of the indexing table depends on its internal mechanism, with mechanical blocking, using gears, we can reach **accuracies of $\pm 1,5$ arcseconds** [3]. A worm screw makes the transmission of the rotary movement. A servo engine moves the worm that transmits the rotary movement to the gear that repositions the table until it reaches the required angle.

1.2.2. Motivation and justification

The Ford VEP (Valencia Engine Plant) is responsible for the **machining of four fundamental elements of an internal combustion engine**: the cylinder block, the crankshaft, the camshaft, and the cylinder head. To realize the pertinent operations on each one of the components, the plant has two types of machines, transfer and machining centers. The transfer machines correspond to older technology and less adaptable, where any small modification of the operation means significant time and monetary inversion. On the other hand, the **machining centers, CNC stations** are much more versatile. This quality allows us to modify different processes when needed, having a greater adjustment to the production changes. This flexibility means a shorter time and money inversion compared to transfer machines, due to only a reprogramming is needed to adapt the machine to perform different operations. To take even more advantage of the modularity of the machining centers, it is usual that these **incorporate an indexing table**. There are different indexing tables types, depending on the number of axes and plates that these have, as we have commented before.

Etxe-Tar provides the CNC machining centers in the VEP. This company is responsible for the manufacture, tuning, and installation of these machines at the production plant. Nevertheless, the **indexing tables are not manufactured by Etxe-tar, but by Fibro**, a German company. In the annex, we can see the distribution of the Fibro tables at the VEP. As we can see, there are tables with different characteristics, 1 or 2 axes, and different orientations of these.

Three years ago, problems appeared with the two axes Fibro indexing tables at the following operations:

Line	Operation	Type of table
Cylinder head	35A	4-645-928-0019
Cylinder head	35B	4-645-928-0019
Cylinder head	35C	4-645-928-0019
Blocs	90A	4-645-928-0019
Blocs	90B	4-645-928-0019

Table 1: Previous problems with indexing tables.

The **contamination of the worm screw lubricant grease** produced the malfunctioning of the tables. The worm screw is responsible for transmitting the rotational movement from the servo engine to the plate. The entrance of the coolant through the lubricant cavities produced the contamination of the grease. This fact caused the loss of viscosity of the grease, and therefore the lack of lubrication, initiating premature wear.

Last November appeared a **problem with the one axis table** placed at the 12th operation of the camshaft production line (from now on OP-12), with reference number 4-166-973-0102. This breakdown occurred **just five years after the installation of the table**, and after the previous experience from the breakdown of the two axes tables, Ford was aiming for a faster and cheaper reparation this time. This intention meant an **in-situ repair**, where a **collaboration** between Ford and Etxe-tar started to be considered. This project is the consequence of the collaboration between these two companies on the repair of this one axis indexing table.

In the annex, we can observe the different Fibro table types installed in the VEP. Together with the second figure of the same annex, we can identify the distribution, quantity, and variations of indexing tables.

This association was interesting for **Ford** because it could **avoid resorting to the manufacturer**, reducing costs and repair time. Ford **VEP engineering department already had experience in this kind of repairs** and its benefits. Electrospindles are a fundamental high-tech component in a CNC that VEP is now capable of repairing after months of learning and investigation. The consequence of this research is a specialized workshop that **repairs electrospindles** not only from the VEP but also from Ford factories all around the world, **saving the company hundreds of thousands of euros**. Nevertheless, the most crucial benefit is the increase of machine availability that these actions represent, **increasing the reliability and maintainability of the production lines consequently**.

For **Etxe-tar**, the alliance was exciting in order to keep its good relationship with its primary customer in Valencia. However, most important, it will help to have a **better understanding of the indexing tables** that the company is installing in their CNC machining centers. With this knowledge, the company could provide **predictive maintenance that enhances the reliability and maintainability** of their machines.

Therefore, what motivates this project is the intention of Ford and Etxe-tar of **increasing maintainability and reliability** of their production lines and machining centers, respectively.

1.3. Application and possible solutions

1.3.1. The functioning of the indexing table

In this chapter, we are going to **focus on the breakdown suffered in the one axis table**. As said before, this indexing table is installed in the OP12 of the camshaft production line.

Initiation of the breakdown: Suddenly, the indexing mechanism started making a **loud noise**, alerting the machine operators. However, because the table was **still working**, they decided to continue with the production until the shift's **end**. And then **replace the table** for the spare one in the warehouse. It is essential to know why the operators did this. The OP12 is the neck bottle of the production line. **If this machining center stops, the whole production line suffers a shutdown**, with the consequences that this implies.

Working conditions: The **capability of the CNC is not a problem**, as not every camshaft goes through this operation; it depends on the camshaft model, as several are made in the VEP. Also, the **requirements of the machining are not excessive**. It consists of a milling process for the QR code of the camshaft to ensure traceability. Therefore, the **forces embedded in the machining process are not demanding**. However, as commented, there is just one machining center that performs this milling, meaning that despite the not critical requirements that the mechanisms handle, any breakdown is significant. This fact is the reason why, as we will see, the **indexing table is over-sized** to guarantee the smallest quantity of failures as possible.

First Actions: The first actions that we had to perform to accomplish our goals were to **disassemble** the table and **understand its internal mechanism**. The following paragraphs are a summary of the functioning hypothesis (**see plan 0 for graphic support**), identification numbers of the different parts in the following paragraphs correspond to identification numbers in the mentioned plan).

Analysis process: When trying to understand the functioning of the table, several theories were made. Unfortunately, in the beginning, we thought that the indexing table had a functioning that was different from the one that it has. First, we are going to explain the mistake that we made, along with the reasons why we committed it. After this, we will explain how we realized our error and the real functioning of the indexing table.

Main movements: The **movements** that the table executes are **lifting and rotating**. As an indexing table, the critical movement is the one that involves rotation. However, to enable this, the table should lift first. This translation comes from the need to ensure **precision when machining**. When the Hirth **coupling (9) is engaged**, we call this, idle position (table is down). However, to be able to **turn, the Hirth teeth must be disengaged**. Therefore the lifting movement is necessary to lift the plate (3) with its Hirth gear and free it.

Lifting movement: The table should **lift approximately 4 mm**, according to the manual, The elementary functioning of the lifting mechanism is the following: The indexing table has a hydraulic **piston (4) that pushes the plate up and pushes it down** when machining the camshaft. We should remark that table does not go to the idle position (down) just because of gravity. We should also **apply a locking pressure**.

Rotating movement: For the **rotational movement**, the table has a **worm screw that transmits the rotational movement to the plate** when this is at its highest position. The worm screw stops when the turn has been completed. Then the table stops moving. Now that

we have explained the basic movements, we can go deeper into the internal mechanism of the table. At this point is where we made a mistake.

Misunderstanding of the lifting mechanism: To transmit the lifting movement to the plate, at the **top of the piston (that does not turn), we find an axial needle bearing (6)**, connecting the piston and the spindle(10). The spindle is attached to the plate with screws. It is necessary to point out that the **plate, the spindle, and the clutch (11) are attached** so that we can think of them like a package or a single piece. At first, we thought that when the table was at idle position, there was some **space between the piston and the bearing**. Therefore the piston had some **stroke length before making contact with the bearing**. This means that **every cycle, the bearing would receive an impact**.

Correct lifting functioning: However, as we investigated more about the functioning, after some test and with the **help of Factoria Solutions** (the company in charge of the maintenance of Etxe-tar's machining centers in the VEP). We saw that it was not reasonable that there was a space between the **bearing and the piston**. They must always be **in contact**, or with minimum space between them when the rotary table is down (hundredths of mm). This correction means that the **hypothetical impact that the bearing was receiving is dismissed** or significantly smaller, something that seems **more logical from the designing perspective**. Once we have amended our mistake related to the lifting mechanism, we could start analyzing the other fundamental displacement.

One last important aspect to consider is that **lifting stroke limiters are crown teeth** (that gear with clutch's teeth) **when lifting and inferior Hirth gear** (360 teeth gearwheel attached to the base) **when descending**.

Rotating mechanism: In the rotating movement, the pieces involved are: plate, spindle, clutch, worm screw, and positioning couplings at the top with 360 teeth (one gear attached to the plate and the other one to the base, one tooth = one degree). This is the **Hirth coupling that gives the table the needed precision**. When the table is at idle position (**down**), **the couplings are geared**. Leaving the crown gear (12) from the worm screw mechanism and the **clutch disengaged**. The opposite happens when the **table is lifted**, the **clutch and the crown gear are geared**, leaving the **precision gearwheels disengaged** and enabling the rotation when the engine moves the worm.

Now that the mechanism of the table is clear, we must focus on the reason for the breakdown, analyzing its consequences, and possible measures to avoid the reproduction of the problem.

1.3.2. Breakdown analysis

1.3.2.1. Ishikawa analysis

Before dismounting the table, an Ishikawa was made to determine the possible causes of the loud noise that the indexing table was making [4].

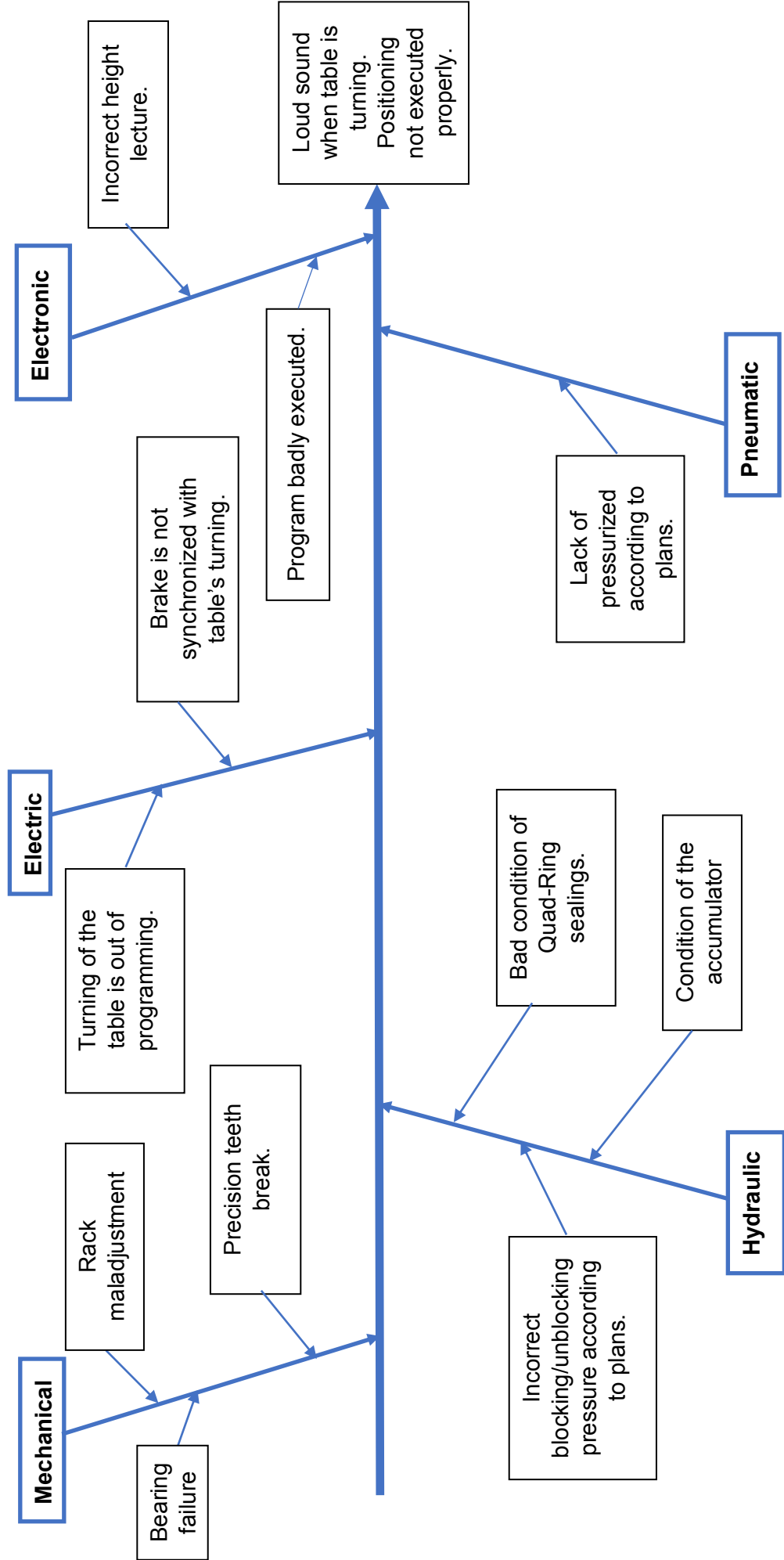


Figure 1: Ishikawa diagram

Corrective measures	Check	State	Observations
Mechanical			
Bearing failure.	X	Broken.	It could be the reason for the noise.
Rack maladjustment.	X	Good conditions.	There are no signs of wear or lack of lubrication.
Precision teeth failure.	X	Good conditions.	No signs of wear.
Electric			
The turning of the table is out of programming.	X	Program OK.	Turning is precise.
Brake is not synchronized with the table's turn.	X	Program OK.	No discordances found.
Electronic			
Program badly executed.	X	Conditions well programmed.	Real conditions are considered.
Incorrect height lecture.	X	Sensor OK.	Table turns at top position.
Hydraulic			
Incorrect blocking/unblocking pressure according to plans.	X	Pressure Ok	Does not exceed max. working pressure.
Bad condition of Quad-ring sealings.	X	Quad-rings OK	Right conditions to be mounted again.
Condition of the accumulator.	X	Pressure OK.	Pressure according to plans.
Pneumatic			
Lack of pressurized according to plans.	X	Pressure OK.	Pressure according to plans.

Table 2: Ishikawa analysis check.

Conclusions after Ishikawa analysis: When opening the table to see what failed, we confirmed that the noise's reason was the broken bearing. Because of the severity of the damage, the spare table needed to be installed in the production line to ensure that production would not suffer a prolonged shutdown.

Spare table check before mounting: Before mounting the spare table in the production line, we tested it to be sure that it was working correctly. While doing these, we paid attention to the lifting stroke. This would be our reference point for the repair of the broken table, as the manual indications just mentioned a lifting height of approximately 4 mm, omitting tolerance. The result of the measurements was that the spare indexing table had a lifting stroke of **4,55 mm**.

Once the camshaft production line was working, we continued dismantling the table to see which components were affected by the breaking of the bearing, and to analyze the state of the bearing itself.

1.3.2.2. Damaged components

Broken bearing analysis: The needle bearing located between the spindle and the piston was in deplorable conditions. The **cage was destroyed**, unable to guide the rolling elements; the **needles were dispersed around the cavity**; and, there was **no trace of an inferior bearing washer**. Figure 1 helps to understand the condition of the bearing.

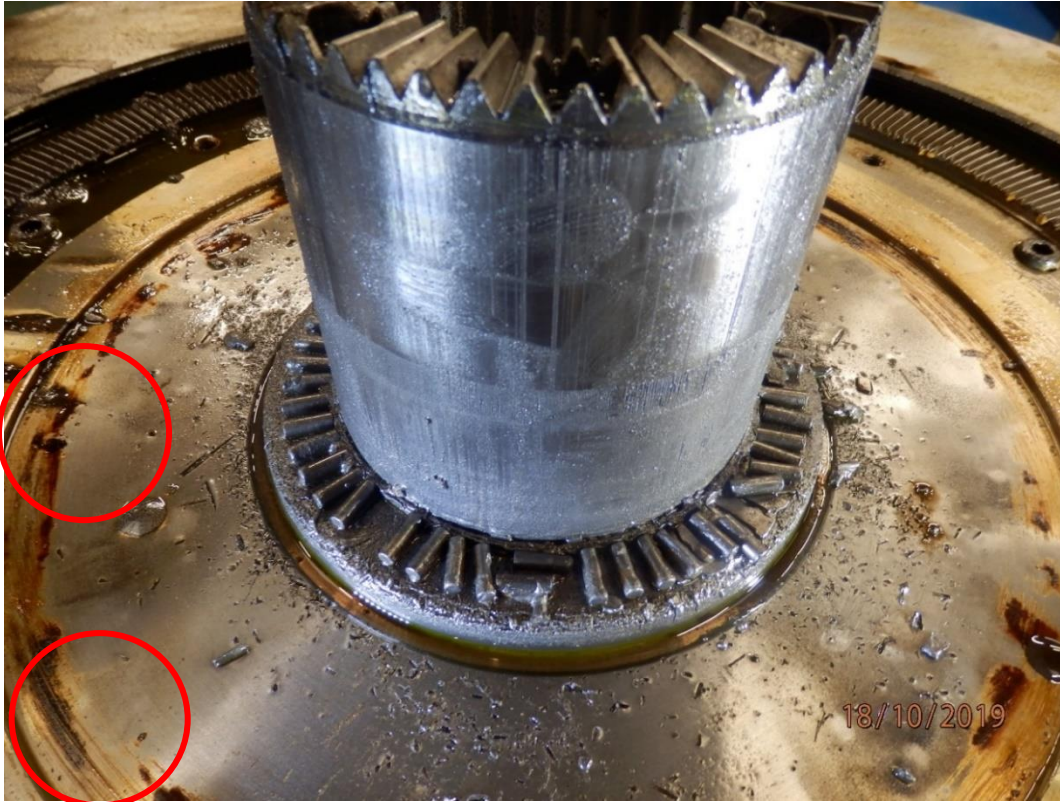


Figure 2: Bearing conditions and temperature marks.

Grease analysis: Also, the bearing had a **per life grease that seemed contaminated** due to its viscosity and its bad smell. It looked like the compound was a **mixture of grease and oil**. However, the machine had no leaks while working in the production line. This fact made us think that **possibly, the Quad-ring sealing between the upper hydraulic chamber and the bearing housing failed** (19) (see plan 0), producing the mixture of the hydraulic oil and the grease. This combination could have initiated the wear of the bearing. However, as seen in the Ishikawa, the **sealings were in usable condition**, even more, there was **no need to replace them** when assembling the table again.

Grease condition explanation: Therefore, the only **reason for the bad condition of the grease was the high temperatures** produced by the friction between the bearing shavings and the plate. We arrived at this conclusion when noticing the **temperature marks** that we can see in figure 1. The working temperature range of the grease (Isoflex NCA15) goes from -50°C to 120°C [5]. According to the mentioned marks, it is reasonable to think that the **temperature was higher than the recommended**, producing the degradation of the grease.

Piston analysis: If we continue scoping the consequences of the breakdown, figure 2 shows that the rolling elements left **deep marks on the piston**. These marks could mean that the bearing was mounted without an inferior washer. A hypothesis that we already mentioned, as we did **not found an inferior washer when first opening the table**. This assembly implies that **the table was incorrectly mounted, in case that the piston did not have proper heat treatment**.



Figure 3: Damaged surfaces.

Parts with damaged surfaces: Also, the breakdown damaged other components of the table; these were **cylinder lid, antifriction sleeves, and spindle**. These were affected by the shavings of the bearing washer and cage that eroded their surfaces.

Once we analyzed the condition of the indexing table and its components, we were able to start seeking for the cause for the breakdown. As far as we know, it started making a loud noise. However, it worked until a programmed shutdown of the production line. When we opened the table, we saw that the scraps of the bearing produced the noise. Nevertheless, now we should find why the bearing was so severely damaged after such a short working period.

Loud noise → Broken bearing → Reason for the broken bearing?

1.3.2.3. Possible causes of the breakdown

As a result of the exposed facts and the experience of Ford's team, Factoria Solutions, and Etxe-tar, we concluded that the following list summarizes all **possible causes of the breakdown**:

- Lack of maintenance.
- Impact when lifting.
- Incorrect design.
- Incorrect use in Ford.
- Incorrect mounting.

Analysis of possible breakdown causes:

Lack of maintenance.

According to the manual that Fibro facilitated when acquiring the indexing table. Maintenance of it is quite limited:

Oil change (worm gear) → every 16000h

Checking of the worm gear backlash → 2000h

Hydraulic joints → Must be checked every 12 months, and changed after 6 years (including max. 2 years in-store).

The oil change and the checking of the worm gear backlash have no relationship with the breakdown. However, the **maintenance involved with hydraulic joints is critical**. As said before, in case the joint between the upper hydraulic chamber and the bearing's placement failed, the oil could have gone up into the bearing's chamber and contaminate the grease by reducing its viscosity. The decrease of viscosity could have produced the breaking of the lubrication film, increasing temperature, and friction, and in conclusion producing premature wear in the bearing, initiating the breakdown. **Etxe-tar also informed that other clients reported to the company that sealings failed**. However, in none of these cases, the failure of the sealings produced damage to the bearing, the main problem was the **leaks caused by the sealing's wear**. Those produced that the indexing **table was not able to lift and rotate**. This scenario is **not ours, as our table could lift** when the breakdown occurred. In conclusion, after the complete analysis of the information, **Ishikawa, and Etxe-tar's reports**, we can conclude **that sealings were in proper conditions** and that they did not have imperfections that we could not appreciate. Therefore, the **lack of maintenance was not the reason for the breakdown**.

Impact when lifting.

In case that the bearing suffered an **impact on each cycle**, this could be the leading cause of the breakdown. However, as we pointed out when reviewing the functioning of the table, this **does not sound reasonable when designing the table**. Nevertheless, as **Fibro did not provide any information according to the designed functioning**, this could be an aspect that they did not consider. At this point, it was **not reasonable to dismiss this hypothesis completely**. First, a more in-depth analysis is needed, where measures of the components are taken. Before that, we should review all possible causes of the breakdown to identify the most probable.

Incorrect design of the bearing.

We should also think about an incorrect design. The **bearing could not be adequately calculated**. If this is the case, the bearing could have failed at any time. To analyze this possible cause, using the reference of the **bearing (AXK130170)**, we contacted the manufacturer (Schaeffler) and tried to acquire it. However, Fibro had the reference blocked; this means that we had to buy the bearing to Fibro because the manufacturer was not allowed to sell the bearing to any company, a factor that increased the price substantially. Finally, we **bought the bearing** for 1600€. We thought that it was essential to have this element to be able **to analyze it entirely** and see possible weaknesses that could interfere with the proper functioning of the indexing table.

Bearing's characteristics: The first fact that catch our attention was that the **bearing washers had a thickness of just 1 mm**. Secondly, **the package included two washers with an inner diameter of 130 mm** and the rolling elements with their cage. However, when **dismounting the table, we found just one washer**. This set up makes sense since the correct mounting in case of having two washers is to adjust one to the rotating element and adjust the second one to the fixed component. This way, the correct functioning of the bearing is ensured. Proper working conditions cannot be accomplished by having the same inner diameter in both washers.

Summarizing, we confirm **that Fibro mounted just one washer**, with a thickness of 1 mm and an inner **diameter of 130 mm that adjust to the spindle**. The rolling elements were 5 mm diameter needles confined in a steel cage. Once this was clear, it was time to analyze **the loads** that the bearing had to handle to see if it was working out of its recommended working conditions.

Bearing designation	AXK130170	
Inside diameter	d	130 mm
Outside diameter	D	170 mm
Width	B	5 mm
Basic dynamic load rating	C	133000 N
Basic static load rating	C0	840000 N
Fatigue limit load	Cu	77000 N
Limiting speed	N Ref	1900 rpm
Limiting speed, oil	N lim. Oil	1900 rpm
Limiting speed, grease	N lim. Grease	475 rpm

Table 3: Original bearing properties [6].

Loads and speed: Table 3 shows limiting loads and speeds of the rolling elements with its cage, according to the manufacturer (Schaeffler). In our case, the **load that the bearing is supporting** is the weight of the plate, the clamping fixtures, and the machined camshafts, in total 1776 kg (**17422 N**). As we can see, the **load is small compared to the limits** showed above, even **smaller than the fatigue limit load**. This fact means that the **bearing is not going to suffer from fatigue** [7]. Also, the **limiting speed with grease lubrication is 475 rpm**. According to the instruction manual provided by Fibro, the **maximum speed** at which the indexing table should rotate is just **32rpm**, again a lower value than the limit.

After this analysis, we can conclude that the **axial needle roller and its cage were calculated correctly**. In fact, they were **oversized**, due to the vast difference between limiting values and real forces and speeds that they were handling, being the limiters much bigger. Even more, we can **dismiss a failure due to fatigue**.

However, we were **concerned about the small thickness of the bearing washers**. Also, we wanted to check the real behavior of the bearing instead of just trusting the analysis made by the manufacturer. These are the reasons why we decided to make a **finite element analysis with Ansys** to watch the performance of the washer and the axial needle roller watching for deformations and stresses.

Ansys simulation: We have also modeled the inferior washer of the bearing and did not model the cage as this is a **static simulation**, and the cage does not handle any stress. We also faced a node limitation with a maximum value of 32.000 because Ansys' license was academical. Therefore, we had a substantial element size limitation, not being able to reduce it as much as we wanted. However, we can assume that **results are reliable**, with an element

number close to the maximum allowed, and **consistent mesh quality**. We can justify this by **looking at the skewness of the elements** [8].

Mesh quality: According to Ansys' standards, a skewness under 0,5 means that the element is functional, between 0,5 and 0,75, it is fair, and over 0,75, the element is poorly shaped. We can see in chart one that most of the elements are under 0,75. Nevertheless, there are elements over this value, but these correspond to elements that make up the mesh of the inferior surface, which is not of our interest.

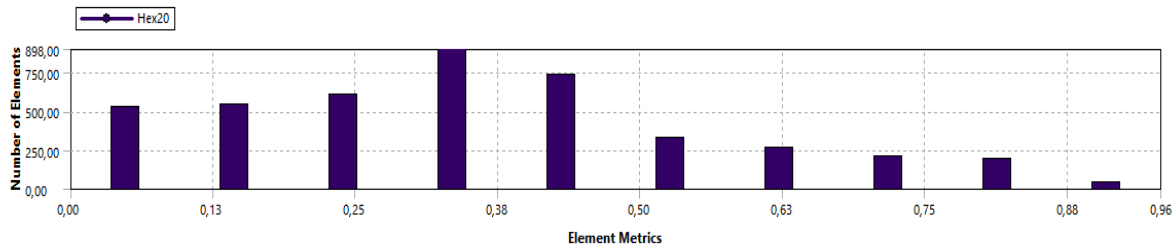


Chart 1: Original bearing mesh quality.

The following images summarize the analyses:

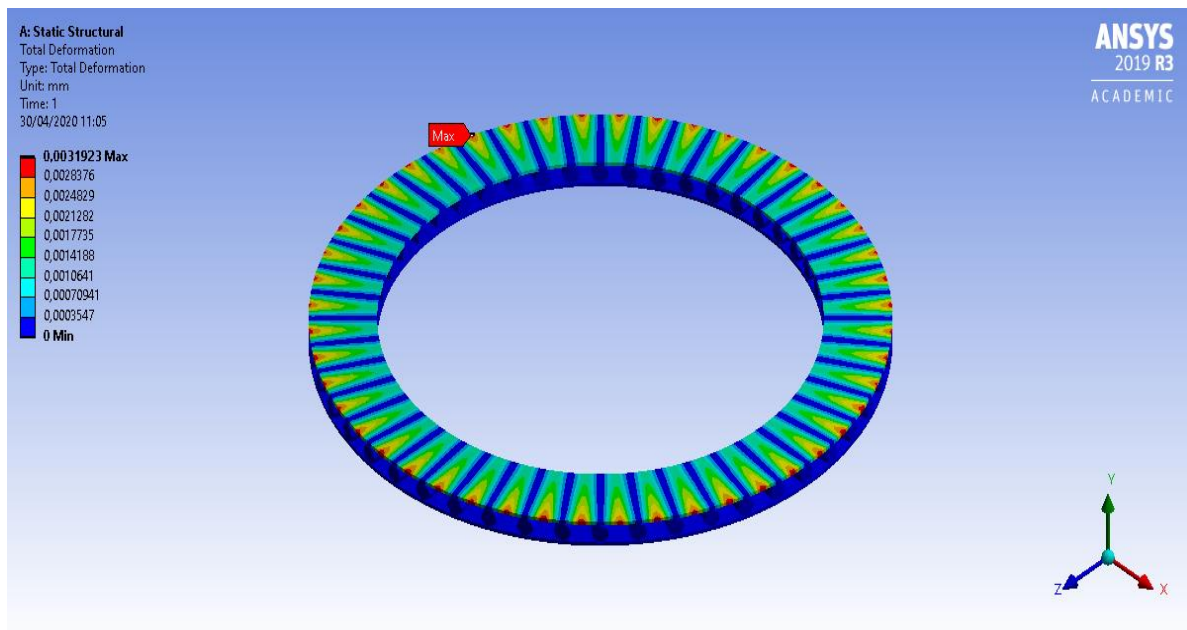


Figure 4: Original bearing deformations.

Deformations: Figure 4 shows the deformation suffered by the bearing when applying the force that corresponds to the weight of the clamping tools, the plate, and machined parts. As we can see, **deformations are small**, with a maximum value of just **3,19µm**. This value seems reasonable according to the applied load and the material; this is EN 1.3505 [9], hard steel used for bearing manufacturing. Also, higher deformations are placed where they are supposed to be, at the superior surface, between needles, where there is no support for it.

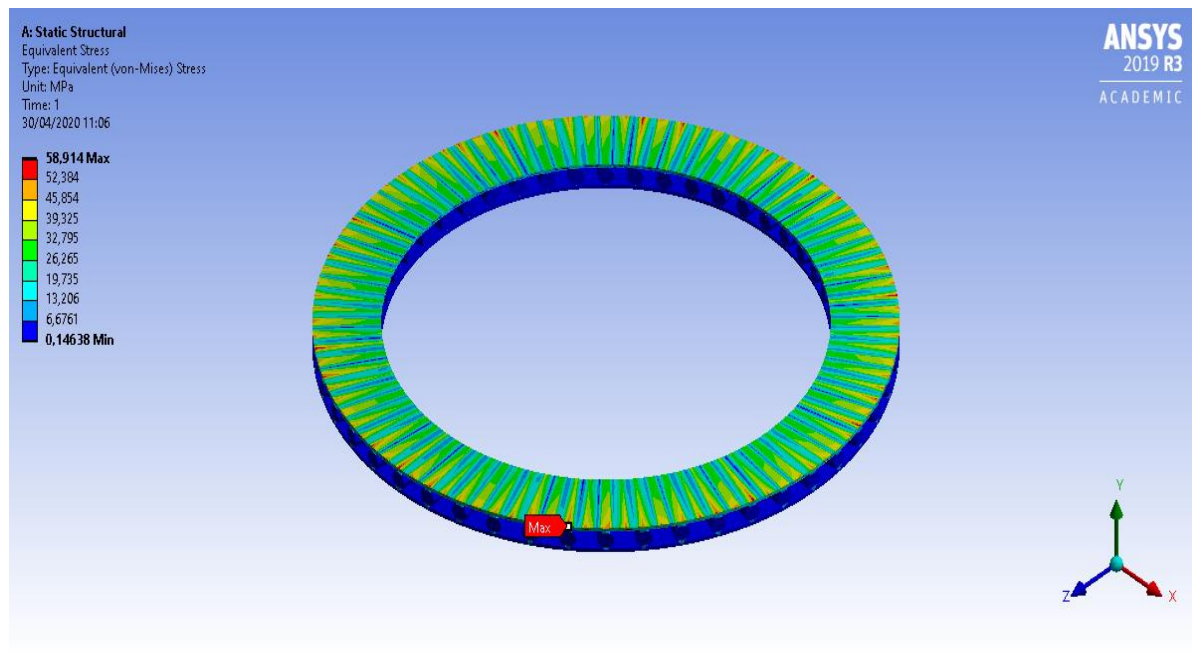


Figure 5: Original bearing stresses.

Stresses: Figure 5 shows the **maximum stresses** that the bearing is handling. With a maximum value of **58,914MPa**. This small stresses that coincide with the **oversized conclusions** of the manufacturer's analysis. Also, maximum stresses are placed in the superior surface, in those zones over the rolling elements, as expected, as the material in these zones is not able to deform to redistribute stress.

After this analysis, we can confirm that the assembly conformed by the **axial needle rollers and its washers were designed correctly.**

The **incorrect design of the bearing was not the reason for the breakdown.**

Incorrect use in Ford.

Here we are trying to see if the table was working out of the **recommended specifications**, especially **blocking and unblocking pressure** of the hydraulic cylinder and **turning speed**. As we said, this operation is the bottleneck of the camshaft production line. There is just one machining center in this operation, responsible for machining the surface where the QR code is placed to ensure the camshaft's traceability. It could be that to reduce cycle time, machine operators increased the cylinder pressure or modified the machining program to increase rotational speed, making the table work out of specifications. **The limiting speed and pressure values** provided by Fibro are:

Maximum working pressure: 30 bar.

Maximum indexing speed: 32 rpm.

We also **checked with** the engineer in charge of the indexing tables in **Etxe-tar**, to ensure if these **values were reliable**, or they could cause long-term problems. He explained to us that the **speed value was correct**. Regarding the pressure, **tables were able to work even at 35bar**. With this information, we checked the working conditions in the production line.

Working pressure: 25 bar.

Indexing speed: 15rpm.

Therefore, as we can see, the indexing table was working according to the optimal working conditions. In conclusion, we can also **dismiss the incorrect use in the production line as the reason for the breakdown.**

Incorrect mounting

As we confirmed before, **just the superior washer was mounted** in the axial needle bearing between the spindle and the piston. This assembly implies that the **component that substitutes the inferior washer (piston) should have unique characteristics**, in order to keep the axial needle roller and its cage in optimal conditions and avoid early wear. The **essential characteristics of the surface** in contact with the rolling elements **must be** [10]:

Hardness: 58-64HRC.

Rugosity: Ra0,2.

Depth of the hardening: 2,54 mm.

$$\text{Depth of the hardening} = 140 \times \frac{DW}{Rp0,2} = 140 \times \frac{5}{550} = 1,27mm$$

Dw=Rolling elements' diameter.

Rp0,2: yield point (material description in the following paragraphs).

Rugosity of the guidance of the cage: Ra0,8.

Rugosity check: It was **impossible to measure the Ra** of the piston's surface in contact with the needles, as it was utterly irregular **due to the marks that the rolling elements left** on it. Figure 6 shows that the surface of the piston had severe damage, which did not allow us to identify the real distance between this surface and the top of the piston.

Functioning check: Because **we could not measure the distance between the piston's surface in contact with the rolling elements and the top of the piston, we could not determine the original design of the table.** Therefore, we could not conclude **if there was an impact when lifting or not.** If we knew the depth of the piston's surface where the bearing relies on, we could find out the total height of the bearing-piston package and determine if there was still space between the bearing and the spindle when the table is mounted (see plan 0). We should wait for the information from Fibro. However, **we will assume that there is no impact to continue with this analysis**, as is the most logical option from a designing point of view. We will **also consider that the rugosity was according to Schaeffler.**



Figure 6: Damage of the piston.

Hardness check: Because the other **critical factor was the hardness of the surface**, we measured this on the piston's surface in contact with the needles, with a result of 238HB, which is just **22HRC**. This hardness is much lower than the **minimum required (58HRC)**. It could be that the piston had a superficial heat treatment, but this critical face could have lost it because of its wear. To check this, we made **measurements on all surfaces of the piston**, and the results were similar, with a hardness **average of 20HRC**.

Material determination: When we had all measurements made, we compared hardness average with the **characteristic hardness of different commercial steels** to see if they would match or if this hardness was the result of special heat treatment. After the search, we concluded that the **material of the piston could be Inox. Steel EN 1.4057** quenched at 980°C and tempered at 565°C, which has a **hardness of 239HB (23HRC)**. A value close to the one obtained in our piston. However, because **hardness is not enough to confirm the material** of our piston, we **continued scoping the characteristics** that EN 1.4057 has. This steel is suitable for applications that require **good wear resistance and highly polishable surfaces**. Two properties that are **fundamental for our application** and that we will justify later on this document. Therefore, we can **conclude that EN 1.4057 is the material of our piston**. Table 4 summarizes the main properties of this material:

Chemical components of EN 1.4057 [11]:

Cr:15-17% Mn:1,5% Ni:1,5-2,5% Si: 1% C:0,12-0,22%

Material	Yield strength (Mpa)	Tensile strength (Mpa)	Elongation (%)	Hardness (HB)
EN 1.4057	550	850	13	239

Table 4: EN 1.4057properties [11].

Once the material and the characteristics of the piston were clear, we concluded that the piston's surface in contact with the rolling elements needed to have **a specific treatment** to ensure the proper functioning of the bearing. This condition took us to analyze the **possible procedures to increase hardness** [12]:

Nitriding: This process reaches high hardness, but with a **maximum depth of just 1 mm**. Due to the limited depth, this process does not apply **to our component**.

Superficial hardened: The **hardness of this treatment goes from 40HRC to 55HRC**. Although it is close to the minimum required by the bearing manufacturer (58 HRC), we cannot conclude that this is enough to ensure the good functioning of the bearing. However, the maximum depth of this procedure is 10 mm, more than enough for our piston. Nevertheless, as we cannot consider this process as appropriate, due to the **lack of hardness** that it provides, this treatment is **not valid** for our piston.

Cementation: This process applies to steels with a low C proportion (<0,25%), this is not a limiting factor for us, as EN 1.4057 has a maximum proportion of C of 0,20%. The **maximum reachable depth of this procedure is 2-3 mm**. This factor is also not limiting, as our **required depth (1,27 mm)** is under these values. At last, the hardness that we can achieve with this **procedure goes from 55HRC to 62HRC**, which is also inside the required range that the bearing manufacturer **demands (58HRC-64HRC)**. However, **cementation cannot be applied to one specific surface of the component** due to the required procedure to implement it. This process consists in introducing the piece in an oven at high temperature (870°C-925°C) with a carbon-rich atmosphere. The C dissolves into the surface, and through diffusion, it goes into the component. Afterward, the piece is hardened. In conclusion, **after this process, all surfaces have the same hardness**, this fact implies that if this were the treatment applied to our piston, **the hardness of the whole part would be more than 55HRC**. This is not our case. In conclusion, **this process would reach the demanded specifications, but it was not applied to the piston**.

What we can extract from this analysis is that either **Fibro did not treat the piston, or a superficial hardened was made but not reaching enough hardness to house the bearing**. We think that the most probable scenario is the second because not treating the piston at all would have been a significant mistake. It would mean that Fibro completely forgot about the minimum functioning requirements of a bearing.

The piston's surface in contact with the rolling elements of the bearing did not have the required hardness.

To conclude this analysis, we must mention that **temperature marks** were found in the piston (figures 7 and 8). These are the result of **the hardening of the EN 1.4057**, not from the possible hardening made by Fibro.

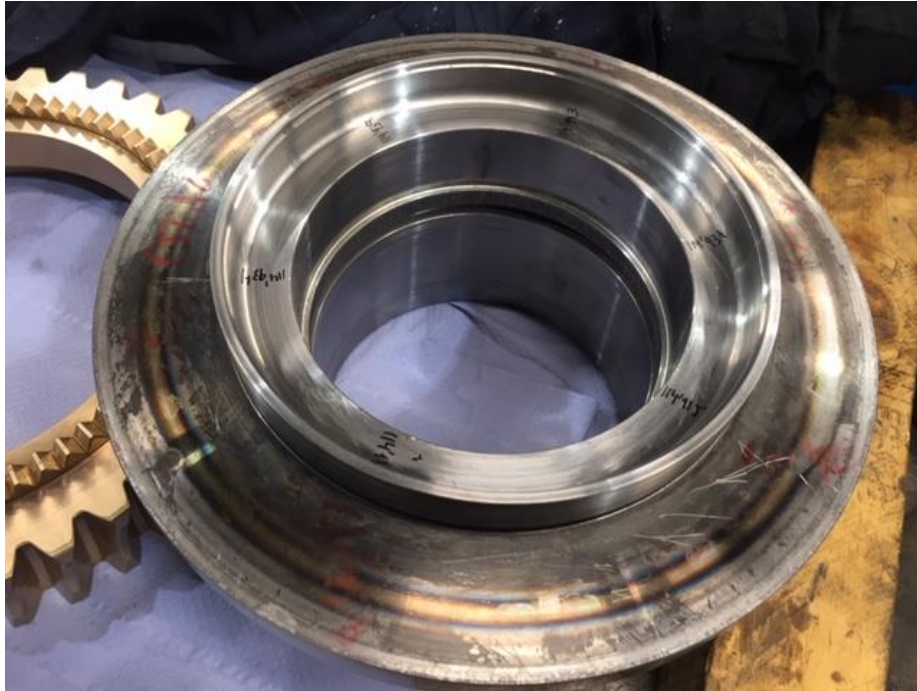


Figure 7: Superior temperature marks.

These marks are the **result of an induction hardening process** [12], where two spirals contacted these surfaces of the piston. The use of two spirals is justified by the need to cover the whole piston without using a spiral with an excessive diameter.



Figure 8: Inferior temperature marks.

Consequences of the incorrect mounting: The lack of hardness caused that the **rolling elements deformed the piston's surface** due to the stress produced by the weight that the bearing had to support. This deformation made the surface irregular, contributing to an **irregular distribution of the lubrication grease** with the corresponding wear that this implies. Also, **if the surface is irregular, the rolling of the bearing is not uniform**, making the **cage of the rolling elements suffer high stresses**. With each cycle, the deformation increased, multiplying the mentioned stress of the cage, and the incorrect distribution of the grease. These higher solicitations produced the **cage's breaking**, the **shavings from it contaminated the grease** and were distributed around the bearing's housing and the space between the plate and the cylinder lid. As said before, these **shavings produced friction between the lid and the plate, creating the temperature marks found in the plate** and degrading the grease by high temperatures. While this was taking place, the cage continued breaking even at a faster pace, as the lubrication grease had lost its properties, and deformations continued increasing. **These facts explain the loud noise** that the table was making that alerted machine operators.

Incorrect mounting conclusion: **The incorrect mounting of the bearing with just one washer explains the breakdown** suffered in the indexing table of the OP12 from the camshaft production line. It is worth it to be said that it does not matter if there was an impact when lifting or not. As we said at the beginning of this point, we are assuming that no impact took place. Nevertheless, the mentioned incidents would also take place if there was. To make this document clearer, we are going to **assume from this point**, that the **bearing did not suffer an impact when performing the lifting movement**.

1.3.3. Repair and modifications

1.3.3.1. Repair

As said, the bearing decomposition damaged several surfaces from different components of the table. The first step was to repair these surfaces in order to be able to mount the same components again, without any need to buy new parts with their extra costs. The **affected pieces were piston, spindle, antifriction sleeves, and superior lid.**

Superior lid repair: Unfortunately, the superior lid was **too damaged to repair it**. Therefore **another lid with the same dimensions was made** in the workshop. This way, we could avoid asking the manufacturer (Fibro) to sell us a new one, reducing costs and waiting time. The **material used** in the manufacturing of this part was steel **EN 1.6563**. We used this material because it had the right characteristics for the application. It has a **high yield strength, preventing the material from deforming when mechanizing it**, a fact that could introduce interferences between the components of the table, due to the small space between them.

Crown gear support, plate, and inferior lid material: If we analyze the stresses that the plate and the crown support handle and the properties that their material should have, we can see that again, steel **EN 1.6563 match the required characteristics**. In conclusion, superior lid, crown support, and plate are made from the same material. The table submits the **inferior lid to smaller stresses**; therefore, steel **EN 1.1203 would be enough**. However, to **ensure the proper functioning** of the table and avoid any oil leaks, as the inferior lid keeps the oil from the carter (cavity that houses the worm screw) from going out. We think that it is **reasonable that EN 1.6563 is also used for this component**, table 5 exposes its properties:

Significant components of EN 1.6563 [13]:

Ni: 1,65-2% Mn: 0,7- 0,9% Mo:0,3-0,4% Cr: 0,7- 0,95%

C: 0,37-0,44%

Ni-Cr-Mo alloys usually also have exceptional resistance against corrosion

Material	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	Hardness (HB)	Toughness (J at 20°C)
EN 1.6563	980	835	12	269	34

Table 5: EN 1.6563 properties [13].

Piston repair: On the other hand, we were **able to machine and repair the damaged surface** from the piston where that housed the bearing. Moreover, we decided to **increase the housing space** to place a wider bearing with its washers.

Spindle repair: The spindle had **two damaged surfaces**, the one that is directly in **contact with the superior washer**, and the surface in **contact with the antifriction sleeves**, we can see this damage on this surface in figure 9. We repaired the surface in contact with the washer **in the workshop**, but the **other one had a rugosity of Ra0,1-0,2** that was not possible to achieve with Ford's machines. It was **necessary to send it to an external company to machine it to perform a chrome plating**.

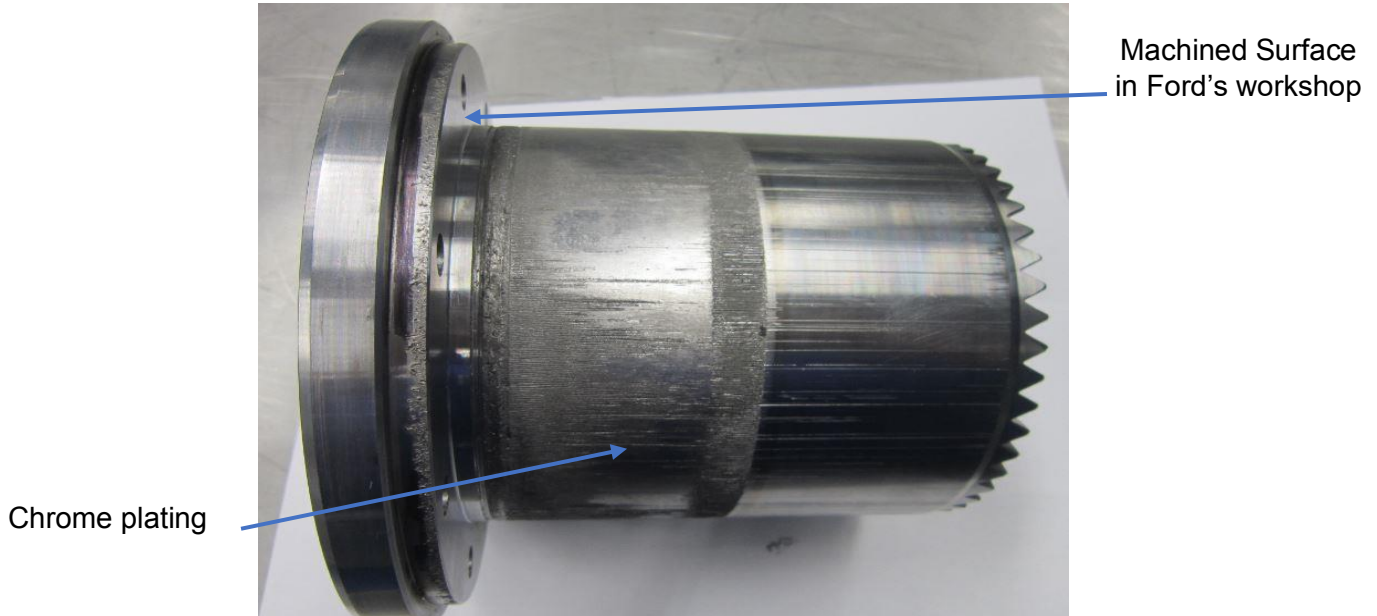


Figure 9: Differences in the spindle damaged surface.

Antifriction sleeves repair: Lastly, regarding the antifriction sleeves, we can find these between the spindle and piston to avoid friction. We can find a sealing between the two sleeves (21) (see plan 0). Because of this sealing, the inferior sleeve was in much better condition, as no shavings from the broken bearing could go between it and the spindle. However, as the **bearing housing and superior sleeve cavity are the same, cage shavings went between the sleeve and the spindle, damaging** as said, the spindle surface, but also the **antifriction component. We could not repair this component;** therefore, we **bought a new one**. This part corresponds to the **EGB13560-E40**, which is composed of **three layers, steel, bronze, and PTFE** (polytetrafluorethylene), with inert additives that conform the E40, the sliding surface. The **distinctive characteristic of this antifriction** component is that **it does not need lubrication**. However, experienced mechanics recommend applying a thin layer of lubricant oil when mounting it. The **recommended tolerances**, according to the manufacturer (Schaeffler) are exposed in tables 6 and 7:

Axis:

Diameter	<5	5<d<80	80≤d
Tolerance	h6	f7	h8

Table 6: Axis tolerances for antifriction sleeves [14].

Housing:

Diameter	≤5,5	5,5<d
Tolerance	H6	H7

Table 7: Housing tolerances for antifriction sleeves [14].

Consequently, the **spindle should have an h8 quality**, and the **inner diameter of the piston an H7**.

1.3.3.2. Modifications

Modification: As said before, **we modified the housing of the bearing**. The modification consists of **increasing the depth of it from approximately 3 mm** (surface was too damaged to make a precise measure) **to 17 mm**, always ensuring that we do not modify the diameter of the bearing’s housing when machining. The H9 quality requires that the diameter should be between 170,000 and 170,100 mm. Nevertheless, this modification left a thin piston wall that could break easily with a radial oriented force. To avoid fracture, we made a **radius of 4 mm at the end of the housing to eliminate any stress raiser**. We must mention that the table design is prepared to handle axial forces that are not a problem for our modification. However, we took every precaution in order to ensure that the piston is not going to break when installing or uninstalling the indexing table. These are situations where it could suffer impacts from different angles.

Modification consequences: The depth increase of the bearing’s housing allows us to **mount a wider bearing with two washers**. The thickness of the washers was not, in principle, a problem. However, we considered that any small malfunctioning of the mechanism could easily break the 1mm thick surface. Therefore, we decided to mount a bearing with an **inferior washer of 9 mm**, a **superior washer of 5,9 mm**, and rolling elements with a 12 mm diameter. Initially, the two washers were 9 mm wide, but we had to **mechanize one of them to fit the whole set** into the table. Also, the **inner diameter was 130 mm** in both of them. To guarantee the proper functioning of the bearing, we machined the **inner diameter of the inferior washer to 132 mm**. We must remember that we must adjust just one washer to the rotating element. Also, we must consider the **tolerances** showed in table 8 provided by the manufacturer:

Bearing component		Tolerance	
		Axis	Housing
K81126	Guided from the interior	h8	-
LS130170	Guided from the exterior	Free axis	H9
	Guided from the interior	h8	Free housing

Table 8: Tolerances for the new bearing [15].

K81126 corresponds to the reference of the rolling elements, and LS130170 corresponds to the reference of the washers. Moreover, we should consider the following instructions provided by Schaeffler:

- The surface should support the axial discs (washers) over the entire surface.
- The supporting points must be plane and perpendicular to the rotation axis.
- The guidance of the cage should be wear-resistant with a Ra0,8 (properties acquired with chrome plating).**

Therefore, **the spindle will guide the superior washer from the interior**, which means that **this component should have an h8 tolerance**, and its rugosity should be at least Ra0,8. **The piston will guide the inferior washer from the exterior**; this part should have **H9 tolerance** and a rugosity, also at least Ra0,8.

It is necessary to check the **tolerances of the original bearing** (table 9) to compare both specifications and see if we should make any modifications:

Bearing component		Tolerance	
		Axis	Housing
AXK130170	Guided from the interior	h8	-
AS130170	Guided from the exterior	Free axis	H9
	Guided from the interior	h8	Free housing

Table 9: Tolerances for the original bearing [10].

Tolerances comparison: **AXK130170 corresponds to the rolling elements and AS130170 to the washers.** As we can see, **tolerances are the same in both bearings.** Consequently, **there are not going to be adjustment problems** when mounting the new one. Also, there is no interference between the needed spindle's tolerance from the **bearing and the antifriction sleeves, as both need an h8.**

Chrome plating justification: The damaged surface where the plating was applied is the **mating surface of the Quad-ring sealing** between the piston and the spindle. This type of sealing, according to the manufacturer (Trelleborg), needs a mating surface with a **Ra0,4 max** [16]. Rugosity also affects the useful life of the antifriction sleeves; for this reason, it is recommendable to lower it as much as the process allows us. This characteristic is the reason why, initially, the Ra of the component was between Ra0,1 and Ra0,2. We considered that the **necessary reparation procedure was chrome plating;** this treatment is perfect for this application. The **low chrome's friction coefficient** makes it suitable to put it in contact with the antifriction sleeve, even more, when the sleeve is designed to work without lubrication. Moreover, chrome plating **enhances deterioration resistance and hardness** of the surface of the component, two characteristics that ensure that rugosity does not increase with the number of cycles.

Bearings' cages differences: We should also consider the differences between the cages of both bearings, especially their material. The **original cage was made of steel**, but the **new bearing's cage is made of plastic.** This difference could be a problem since some plastics suffer degradation when they are in contact with oils or greases. Our material was **polyamide 66, reinforced with fiberglass.** It is an **extremely stable material;** nevertheless, we asked **BP's (British Petroleum) personnel in Ford**, as they could give us reliable information in terms of **chemical compatibilities.** According to their experience, the **polyamide 66 could mix with the grease that we were going to use**, the ISOFLEX NCA 15. This lubricant is the same grease that Fibro uses when assembling their indexing tables. In conclusion, we could mount the new bearing with guarantees.

Since we did stress and deformation analyses in Ansys of the original bearing, we decided that it would be interesting to do these analyses with the new bearing. Then we could compare the results and look for any possible discordances.

New bearing's Ansys analysis: The followed procedure and limitations were the same as described in the original bearing's analysis. We did not model the cage because of the commented reasons in the previous report. In order to check the quality of the mesh, we have chart 2:

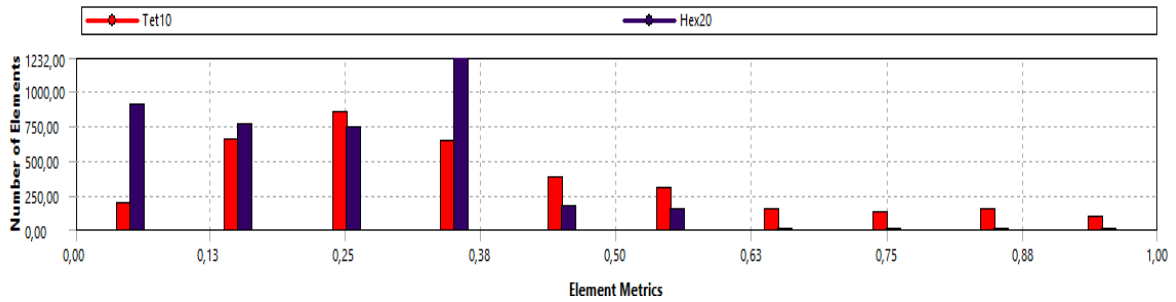


Chart 2: New bearing mesh quality.

In this case, we have two types of elements, tetrahedral and hexahedral, to have a better fit to the shape of the bearing. Also, in this case, the elements over 0,75 are placed in the inferior washer. Now, we do mount this element, but since it is not critical because the force is applied to the superior washer, we consider this **mesh as reliable**.

The following images summarize the analyses:

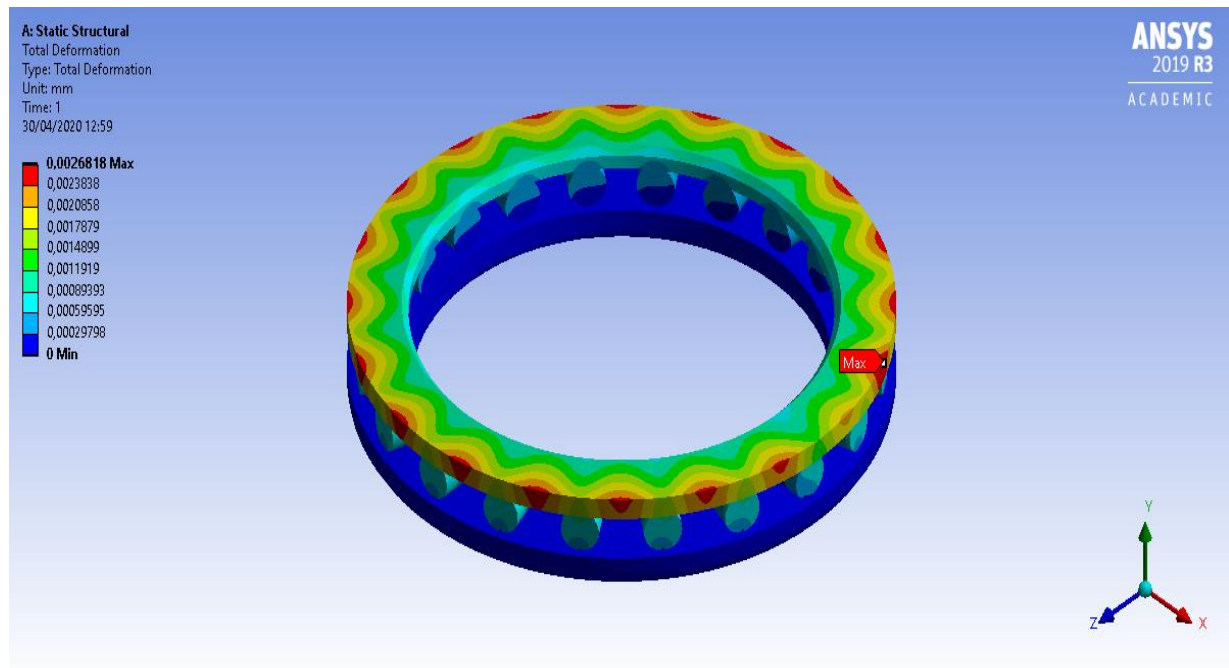


Figure 10: New bearing deformations.

Deformations: Figure 10 shows the **deformation** of the bearing when applying the load. As in the original bearing, the higher deformation values occur in the superior washer, between the rolling elements, with a **maximum value of 2,68µm, smaller than the 3,19µm obtained in the original bearing.**

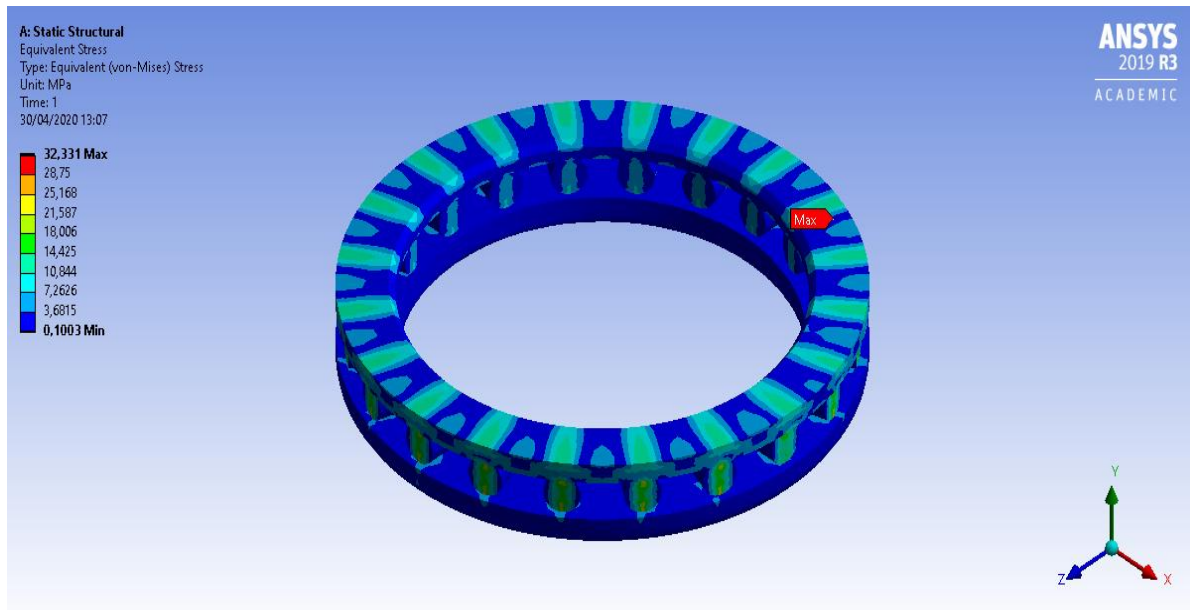


Figure 11: New bearing stresses.

Stresses: Figure 11 shows the **stress** produced in the bearing. Again, the maximum stresses take place in those zones of the superior washer that are over the rolling elements that prevent it from deformation. The **maximum stress value is 32,331MPa, smaller than the 58,114MPa obtained in the original bearing.**

Ansysis analysis comparison: After carefully watching the results, we see that both **deformation and stress parameters have decreased**. Therefore, we have increased the performance of the mechanism. However, these values have not decreased according to the same ratio. **Deformation decreased just to 0,84 approx.** of the original bearing, while **stress decreased to 0,56 approx.** The distance between the rolling elements can explain this difference. In the original bearing, needles were closer to each other than in the new component. This distance's decrease reduces momentum in the middle section between elements, and therefore, deformation.

1.3.3.3. Final checking

Mounting and functioning check: As we repaired all surfaces or replaced the required components, it was time to mount the indexing table. We knew that the **spare table lifted 4,55 mm**; this was our **reference to check if the reparation was well executed**, as the manual just said that the table lifted approx. 4 mm without any tolerance margin.

Modifications summary: We made the **housing of the bearing bigger**. Besides, when **repairing the damaged surface of the spindle that is in contact with the upper washer**, we **reduced its height by approx. 7 mm**. This action should not be a problem, providing that the **bearing is wide enough to fill the gap between this surface and the piston**. Therefore, our bearing set was 26,9 mm thick, after with the modifications that we made on the upper washer. However, we must **ensure that precision teeth gear entirely** when the table is at **idle position**, and prevent possible stress due to dilatation of the materials. Therefore, we left a **minimum gap of 0,04 mm between the superior washer and the spindle**. This space should not make a considerable difference in the lifting stroke. Other critical dimensions for the lifting of the table were not modified. It was crucial not to modify many dimensions of the components. We had to keep track of the repercussion of each modification and not to affect the different mechanisms of the table.

Movement transmitter check: The bronze crown gear needed to be **at the same height** as before because of the need for alignment with the worm for a good transmission and avoid wear. The **crown gear is made of bronze** to avoid **deterioration in the worm**, a fact that would cause a considerable and expensive breakdown. The **bronze used is the EN 1982 CC483K type**, suitable for high resistance and low-speed applications [17]. Bronze EN 1982 CC491K has the same specifications but with poorer mechanical characteristics [18]. The composition of EN 1982 CC483K is:

-85-89% Cu 11-13% Sn Minor components: Pb, Zn, Sb

These Sn, Pb, Sb, and Cu alloys generate small hard small crystals inside the soft matrix to maintain in good conditions the contact surfaces.

Table 10 collects its fundamental mechanical properties:

Material	Tensile strength (Mpa)	Yield strength (Mpa)	Elongation (%)	Harness (HB)
Bronze EN 1982 CC483K	310	152	14	95

Table 10: Bronze EN 1982 CC483K properties [17].

There was no sign of early wear in the crown gear.

Lifting height and comparison with the spare table: According to the manual, the rotary table should lift approximately 4 mm. Nevertheless, after the reparations made and mounted, we connected the table to a hydraulic test rig, and the **table lifted just 3,25 mm**. We did not expect this height, there was a **difference of 1,3 mm between the lifting stroke of the two tables**. Nevertheless, the table was able to turn. After these results, we concluded that we should make **revisions on the reparations**. Moreover, it was also worth **checking the specifications of both tables** to determine if both correspond to the same model. Also, to verify that after the modifications, the table was working correctly, we made a **CAD model** with Inventor. This model would allow us to see if something was blocking the table from reaching its maximum height after executing the modifications.

Revision of the modifications: As commented before, the **modified parts were piston, superior lid, and spindle**. As we sent the **spindle** to an external company to repair the surface in contact with the antifriction component, we had to check if the given **rugosity** was appropriate, it **should be lower than Ra0,4**. The **result was Ra0,2**, under the commented maximum value. Therefore, this reparation was **performed correctly**. The piston's **modifications do not affect the lifting stroke as long as the bearing fills the gap between the piston and the spindle**. The gap of just 0,04 mm does not justify the 1,3 mm difference that we observe.

The last modification to check was the **replacement of the superior lid** by another one manufactured in the workshop. Unfortunately, once we made the new lid, the original was eliminated. Consequently, we could not check this immediately; we should **wait to finish the CAD modeling** to see if this new component was causing interference between components. That would not allow the table to reach either its highest position or its lowest. It could be that our problem was that the table was not reaching its idle position. We could not see this as we made the lifting measurements using a dial indicator placed at the top of the plate.

CAD modeling: The table was able to turn, but we **did not know how much space there was between the upper and lower teeth of the Hirth coupling at the upper position**. The maximum height of these teeth is 3.1mm, and lifting stroke is 3,25 mm. However, we must consider that teeth make contact with their flanks when the table is down. The consequence embedded is that when geared, there is a space between the teeth's top and base. Due to this, we have a higher margin when rotating, but we do not know precisely how much. To clarify this, we made the CAD modeling.

Measures for CAD modeling: We measured every component of the table involved with the lifting movement. Because of the difficulties of the measurement, we used **different tools**. These were: **measuring column, electronic depth gage, and caliper**. The most precise measurements were those made with the gage and the measuring column. We used the caliper to measure the base, the most complicated component, due to its dimensions and weight. Another **complicated measure was the height of the teeth**. The reason for the complexity is that the **teeth's crests and bases are not horizontal, they have a defined lean angle**. This angle implies measurement difficulties. We had to make a **unique tool for the measuring column** that had a smaller angle at the end than the angle between teeth to fit the tool in their base. **This tool would introduce a small error into the measures**, but because of the **precision** of the measuring column in **normal conditions is one-thousandth** of mm, we take **this error as assumable**.

Hirth teeth: The **shape of all gears in this table is known as Hirth teeth**. These are a special kind of teeth used in many industrial applications due to its **accuracy and capability of high torque transmission**. Nevertheless, it is not produced by any standard as DIN, ISO... The **reason for the high precision of this system is the lean angle** that it has. This angle makes the parts that implement these **teeth to form a cone**. This shape implies that when teeth are geared, **parts tend to self-center** [19]. The following plan of the clutch (figure 12) shows the shape of these teeth. That is an approximation, as it corresponds to the drawing of the clutch that we made from the measures that we took. However, it is useful to see the cone form that the teeth create. Both gears (interior and exterior) implement the Hirth system. Nevertheless, because of the exterior teeth' short length and the position of the section, it is not possible to appreciate their shape. However, it is easily identifiable on the internal gear.

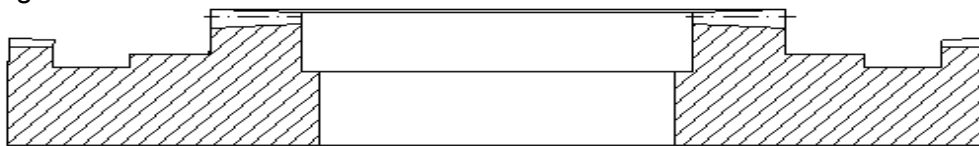


Figure 12: Clutch section.

The **natural material** used for the manufacture of these parts is tempered **EN 1.7225**. Table 11 shows the properties of it [19]:

Significant components of EN 1.7225 [20]:

Cr: 0,9-1,2%

Mn:0,75%-1%

C:0,38-0,43%

Mo: 0,15-0,35%

Si: 0,15-0,35%

Material	Yield strength (Mpa)	Tensile strength (Mpa)	Elongation (%)	Hardness (HB)	Toughness (J min)
EN 1.7225	550	690	18	235	35

Table 11: EN 1.7225 properties [20].

These **teeth are also rectified**, this process can provide tolerances of $\pm 0,001-0,005\text{mm}$ and rugosities of $Ra\ 0,05-1\mu\text{m}$ [21]. These characteristics ensure good contact between flanks, exploiting the whole surface of the tooth, and preventing possible failures due to a stress increase.

EN 1.7225 properties: As we can see, this is a material with excellent **resistance and good toughness**, able to handle high demanding transmissions maintaining the required precision in the process. This material is also used for the manufacture of cram-shafts, rods, Cardan axis, and more. Critical applications where the right material choice ensures the long-term functioning of the mechanism. Another possible material that we could use could be EN 1.6563 with a similar yield strength but with a smaller toughness.

Bronze EN 1982 CC483K justification: However, as we have said, the **crown gear from the worm screw is made from bronze** to avoid damage in the worm. Bronze's hardness is much lower than the mentioned steel. Therefore, we should expect **more significant wear in the Hirth teeth** of the crown gear than in the ones in the clutch. This increase in deterioration justifies the election of **Bronze EN 1982 CC483K instead of EN 1982 CC491K**. This choice **guarantees a longer life** of the mechanism before replacing the crown because of its wear.

After this explanation, we are in the right position to determine that the **blocking coupling with 360 teeth, the spindle, and the clutch are made from the same material, EN 1.7225**.

Base material: Through the previous pages, we have described the materials of all parts of the indexing table but the base. The material of this component is **grey casting (2,5-4% C 1-3% Si)**. It is a **fragile material but with high resistance to wear and capable of mitigating vibrations** with an excellent behavior under compression [22]. These properties, combined with a reduced price, make it **perfectly suitable for our base**. Because the grey casting used in crankshafts according to the SAE J431 is the G4000, and the **base** does not suffer such critical stresses as this crucial component in an internal combustion engine. We can determine that the specific **grey casting type of our base is G3500 with an inferior hardness and yield strength**.

Now we have all parts with their materials, to summarize it we have the following table:

Component	Material
Hirth coupling	EN 1.7225
Clutch	EN 1.7225
Spindle	EN 1.7225
Crown gear	EN 1982 CC483K
Piston	EN 1.4057
Plate	EN 1.6563
Superior lid	EN 1.6563
Crown gear support	EN 1.6563
Inferior lid	EN 1.6563
Base	Grey casting G3500

Table 12: Materials summary.

CAD modeling results: With this information, we continued with the **modeling with Inventor**. The result of it was a **lifting stroke of 3,201 mm, 0,049 mm difference from reality**, a deviation that we can assume that is produced by measurement uncertainty. When

analyzing the model, we observe that **there is no interference between components**. The new superior lid was not the reason for the shorter stroke, and the indexing table could reach its highest and lowest position without interferences. This fact implies that **movement limiters are precision and crown's gear Hirth teeth as expected**. Also, when the table is at the highest position, the **margin between upper and lower precision teeth is 0,951 mm**. If we consider that the real table lifts 3,25 mm, this would mean that we have a margin of exactly 1 mm.

Lifting height difference explanation: There was no reason to think that table would not work correctly, but there was a **difference of 1,3 mm between the spare table** that was working in the production line **and the repaired table** that we could not explain. After these results, **Etxe-tar decided to question Fibro** about some aspects of the functioning that we might not be understanding correctly. We also **noticed** that there was a **5-year difference between the tables' manufacture years**, along with a **40 kg deviation**. We thought that there **could be differences in both designs** that could explain this disparity, but as we did not have the information, we asked Fibro. The company answered **that they did not modify the design** of the indexing table in those years. However, they also said that the **lifting stroke was not important, providing that the Hirth coupling of 360 teeth (1 tooth=1°) can disengage and rotate**. This last information was fundamental. It means that **there is no determined lifting height**. According to the manual, lifting stroke is approx. 4 mm, but from this experience, **±1 mm is acceptable**. In conclusion, 3,25 mm was also the lifting stroke of the indexing table when Fibro assembled it for the first time.

To summarize, these are the **results of the verifications**:

Revision of the modifications: No interferences between components, movement limiters were Hirth couplings as expected.

Deviation between tables: 1,3 mm.

CAD lifting stroke with repaired table measures: 3,201 mm.

Repaired table lifting stroke: 3,25 mm.

With these results, and the information provided by the manufacturer, we could make the following assumptions:

Lifting stroke tolerance: ±1 mm.

Initial lifting height of the indexing table that suffered the breakdown: 3,25 mm.

1.3.4. Conclusions

This **project** involved the mechanism comprehension, the breakdown's analysis, the repair along with the material determination of each part, and the improvement made in the design. All exposed actions **allowed** us to have a **deep understanding of the mechanism and design** of the table. However, the most significant improvement is the capability to **improve the reliability and maintainability of the machining centers, and therefore, the production line**. This project could be the **first step of a workshop in the VEP for indexing tables** that incorporate Hirth couplings as its precision system. This document could also mean **future technical assistance that Etxe-tar could provide** at the many different locations where they have installed indexing tables in their machining centers.

Part 2

2. Bid specifications

This chapter of the document aims to develop the **bid specifications** demanded by this exercise. It implies **exposing the required characteristics of the materials and machinery** that need to be used to perform this project; the **totality of actions** that the executor has to do along with the **recommended techniques to perform them**; and also, the **regulations** that need to be followed to meet international standards and guarantee safe conditions for the workers.

The majority of the regulations that we will outline in this chapter correspond to Spanish regulations, which are adaptations of the standard European rules for all members of the European Union. We just made one exception due to Ford's nature. In this case, the regulation used comes from SAE International (formerly known as Society of Automotive Engineers) standards, that are frequently used in Ford.

Bid specifications index

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2.1. Scope of the project

2.1.1. Regulations

Safety regulations

UNE-EN ISO 16090-1:2017: Machine tools safety. Machining centers, Milling machines, Transfer machines- Part 1: Safety requirements.

UNE-EN ISO 12100:2012: Safety of machinery- General principles for design- Risk assessment and risk reduction.

UNE-EN ISO 13857:2019: Safety of machinery- Safety distances to prevent hazard zones being reached by upper and lower limbs.

UNE-EN 349:1994+A1:2008: Safety of machinery. Minimum gaps to avoid crushing of parts of the human body.

UNE-EN 60204-1:2019: Safety of machinery. Electrical equipment of machines. Part 1: General requirements.

Mechanical and technical regulations

UNE-EN 22768-1:1994: General tolerances Part 1: Tolerances for linear and angular dimensions without individual tolerance indications. (ISO 2768-1:1989).

UNE-EN ISO 286-1:2011: Geometrical product specifications (GPS). ISO code system for tolerances on linear sizes. Part 1: Basis of tolerances, deviations, and fits (ISO 281-1:2010).

UNE-EN ISO 286-2:2011: Geometrical product specifications (GPS). ISO code system for tolerances on linear sizes. Part 2: Tables of standard tolerance classes and limit deviations for holes and shafts (ISO 282-2:2010).

UNE-EN 10020:2001: Definition and classification of grades of steel.

UNE-EN 1982:2018: Copper and copper alloys. Ingots and castings.

UNE-EN 683-17:2014: Heat-treated steels, alloy steels, and free-cutting steels. Part 17: Ball and roller bearing steels.

SAE J431_200012: Automotive gray Iron castings.

2.1.2. Material and machinery description

The execution of this project requires **different machinery, equipment, and tools**. To correctly **classify these**, we have divided the project into **five units of work**, as we have done in the budget. Units of work, materials used and required machinery are:

-**Mounting/Dismounting:** Workbench, workshop crane, crane bridge, tool carriage.

-**Plans:** Electronic depth gage, caliper, measuring column, computer, 3D CAD program.

-**Breakdown analysis:** Finite elements simulation program.

-**Repair and modifications:** CNC lathe, milling machine, honing machine, chrome plating.

-**Tests:** Hydraulic test rig.

2.2. Technical conditions

2.2.1. Machinery, personnel, and material requirements

Machinery and personnel

To correctly develop the project, all units of work should be performed with the personnel, machinery, and material that meet the following characteristics or exceed them.

Mounting/Dismounting:

-Personnel: 1 Adjuster, 1 Assistant

-Workbench: It must enable the mechanics to reach the top and the bottom of the table to perform all operations.

-Workshop Crane: 1 tone max. load.

-Crane bridge: 1 tone max. load.

-Tool carriage: Allen wrenches, screwdrivers set, torque wrench (up to 300 Nm), slide hammer puller, rubber mallet, tensioning screws.

-Plans:

-Personnel: 1 Engineer, 1 Adjuster.

-Measuring tools: Electronic depth gage (precision of 0,01 mm), caliper (precision of 0,01 mm) and measuring column (precision of 0,001 mm)

-Computer requirements:

-CPU: Intel i7-9700K 3,6GHz.

-RAM capacity: 16GB.

-SSD: 240GB.

-GPU: Intel UHD Graphics 630.

-3D CAD program: Inventor professional, 2019.

Breakdown analysis:

-Personnel: 1 Engineer

-Finite elements simulation program: ANSYS 2019 R3.

Repair and modifications:

-Personnel: 1 adjuster, 1 assistant.

-Machinery:

-Parallel lathe: Heller CE500x2000 (2 m bench).

-Horizontal CNC milling machine: Zayer KF3000 (3 m bench).

-Plane honing machine: Jones & Shipman 540P.

-Processes: Electrolytic Chrome plating with final honing (max. Ra0,4).

Tests:

- Personnel:** 1 adjuster, 1 assistant
- Hydraulic test rig:** pressure up to 40 bar.

Worker's safety

To safely perform every action of the project, the following instructions regarding the formation of the workers and the required IPEs must be followed:

Mandatory IPEs:

- Safety shoes:** Always needed at any phase of the project.
- Safety helmet:** Required when installing or uninstalling the indexing table from the machining center.
- Safety goggles:** Required when performing any action on the table or using machining tools as lathes, milling machines, etc. Except when performing the required measurements to create the plans, always in a safe shavings-free environment.
- Anti-cut gloves:** Required when performing any action on the table or using machining tools as lathes, milling machines, etc. Except when performing the required measurements to create the plans, always in a safe shavings-free environment.

Required formation:

- ECPL (Electric Controls and Power Lockout):** This is a safety system used in any Ford production plant, and many other companies. It ensures safe handling of automatic machines, such as transfers or CNCs, through power locks and easily identifiable signs. Every worker must have received a formation in this procedure.

2.2.2. Repair and modification guidelines

-Mounting/dismounting:

- When **dismounting** the table, mechanics should take **photos of the components**. This action will help with the breakdown analysis in further steps of the project.
- Clean all components** to identify every defect on them, marks, deformations, etc.
- Preserve **order at all moments**, classifying sealings, screws, and every component of the table.
- When **mounting** the table after the repairs and modifications, all **components** must be correctly **lubricated and adjusted**. Bearing grease must be Isoflex NCA 15. Worm-screw and piston oils are indicated in Fibro's maintenance guidelines. **When testing** the table, it must be at the **same mechanical conditions as it would be in the production line**. **Partial mountings are not allowed to perform final tests**.

-Plans:

-Mechanics must repeat each **measure at least three times** to extract the arithmetic average. The number of repetitions increases up to **6 when measuring Hirth gear's teeth**. Hirth teeth measures must be made with a precision column, the rest of the measures could be made with caliper or electronic depth gage, depending on the needs of each measurement.

-The engineer must model the table with **3D CAD software**, Inventor or Solid Works, for example. That enables future analysis. The model must include the material of each component.

-**Component plans and assembly must have a 3D view** in order to facilitate the comprehension of the component.

-**Plans must include the material of which the component is made**. That will facilitate further finite element analysis, such as the performed Ansys simulation.

-Breakdown analysis:

-**Ishikawa analysis**: The engineer must perform an Ishikawa analysis to identify all possible causes of the breakdown. He or she must take into account the opinion of the mechanics in charge of the dismounting.

-The **engineer** in charge of the analysis must **rely on the mechanics** to obtain reliable information such as hardness, rugosity, etc. Also, he or she must **keep track of the dismounting process** and ask for any complications.

-**When the reason for the breakdown is apparent, the engineer must explain to the team** involved in the project, the reasoning, and the assumptions made. This action provides a **double check** before continuing with further actions.

-Repair and modifications:

-The team involved must **check the repaired components** to confirm that performed actions meet the required characteristics and that no critical aspects of the component were affected, such as rugosity, or dimensions out of tolerance ranges.

-In case that the **workshop does not have the required machinery to perform the chrome plating**. This process must be commended to an **external company** that could ensure the rugosity requirements. In any case, **rugosity must be checked** after the process to guarantee a **value under Ra0,4**.

-Components that cannot be repaired or manufactured will be replaced by original spare parts when possible.

-Tests:

-Tests must simulate the **exact working conditions of the production line**, cycle time, movement, blocking/unblocking pressures, and indexing speed. These tests must last at least 18 h without any trace of malfunctioning.

Part 3

3 Budget

In this part of the project, we are going to develop the **required budget by Ford** to perform the repair and modification, considering the machinery used, personnel, and invested time. Once we have done this, we will also do an **estimation of Fibro's budget**. Then we will **compare both** investments to scope possible savings. Moreover, we will compare the price of a new indexing table and Fibro's repair budget. That is interesting due to **companies frequently reject reparations when the required budget for these is more than 50% of the total price of the new component**. This condition is a consequence of repair's difficulty, due to their variety and complications that could appear during the process. Besides, the manufacturer must give a warranty period after the repair that could be difficult to ensure. Therefore, **if Fibro's expected budget exceeds 50% of the price of our table, savings will be considered as the difference between the price of a new table and Ford's budget**.

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3.1. Ford's Budget

Price list: employees/ machinery/materials			
Code	Unit	Description	Price (€)
E01	h	Adjuster	36,81
E02	h	Assistant	36,81
M01	h	Adjuster's tools	6,63
M02	h	Assistant's tools	6,63
E03	h	Engineer	64,41
M03	h	Engineer's tools	11,59
M04	Units	Chrome plating	1198,5
M05	Units	Bearing	225,67
M06	Units	Antifriction sleeves	41,47

-IVA is included in the prices.

-The tool's price is 18% of the total price of its owner.

Employees are marked with **green**.

Machinery is marked with **blue**.

Materials are marked with **red**.

Units of work:

1-Mounting/Dismounting: UW1.

UW1: Mounting/Dismounting					
Code	Unit	Description	Quantity	Price	Cost (€)
E01	h	Adjuster	24	36,81	883,44
E02	h	Assistant	24	36,81	883,44
M01	h	Adjuster's tools	24	6,63	159,02
M02	h	Assistant's tools	24	6,63	159,02
Total					2.084,92

2-Plans: UW2.

UW2: Plans					
Code	Unit	Description	Quantity	Price	Cost (€)
E03	h	Engineer	16	64,41	1.030,56
E01	h	Adjuster	16	36,81	588,96
M01	h	Adjuster's tools	16	6,63	106,01
M03	h	Engineer's tools	16	11,59	185,5
Total					1.911,03

3- Breakdown analysis: UW3.

UW3: Breakdown analysis					
Code	Unit	Description	Quantity	Price	Cost (€)
E03	h	Engineer	50	64,41	3.220,5
Total					3.220,5

4-Repair and modifications: UW4.

UW4: Repair and modifications					
Code	Unit	Description	Quantity	Price	Cost (€)
E01	h	Adjuster	40	36,81	1472,4
E02	h	Assistant	40	36,81	1472,4
M01	h	Adjuster's tools	40	6,63	265,03
M02	h	Assistant's tools	40	6,63	265,03
M04	Units	Chrome plating	1	1198,5	1198,5
M05	Units	Bearing	1	265,032	225,67
M06	Units	Antifriction sleeves	2	41,47	82,94
Total					4.981,97

5-Tests: UW5.

UW5: Tests					
Code	Unit	Description	Quantity	Price	Cost (€)
E01	h	Adjuster	24	36,81	883,44
E02	h	Assistant	24	36,81	883,44
M01	h	Adjuster's tools	24	6,63	159,02
M02	h	Assistant's tools	24	6,63	159,02
Total					2.084,92

Budget [23]:

Code	Description	Cost (€)
UW1	Mounting/Dismounting	2.084,92
UW2	Plans	1.911,03
UW3	Breakdown analysis	3.220,5
UW4	Repair and modifications	4.981,97
UW5	Tests	2.084,92
Total		14.283,34
Indirect costs (0,04xTotal)		571,33
Overhead (0,20xTotal)		2.856,67
Inversion's budget		17.711,34

-Markup is not considered as the repair is performed by Ford.

The total cost of the project is:

Seventeen thousand seven hundred and eleven euros with thirty-four cents.

3.2. Fibro's budget

To generate this budget, **we have estimated that Fibro's technicians will need 25% less time**, as they are more experienced and specialized. Also, the base price for their services is 46,01€/h, 25% more than Ford's personnel.

Therefore:

Price list: employees/ machinery/materials			
Code	Unit	Description	Price (€)
E01	h	Adjuster	46,01
E02	h	Assistant	46,01
M01	h	Adjuster's tools	8,28
M02	h	Assistant's tools	8,28
E03	h	Engineer	80,52
M03	h	Engineer's tools	14,49
M04	Units	Spindle	2.684
M05	Units	Superior lid	1.306
M06	Units	Piston	3.042
M07	Units	Bearing	1.660
M08	Units	Antifriction sleeves	41,47

-IVA is included in the price list.

-The tool's price is 18% of the total price of its owner.

As we can see, M04, M05, M06, and M07 are materials that we have not considered in the previous Ford's Budget. This difference is because we assume that when Fibro performs the repair, it does not fix the damaged components but replace them with new parts.

Employees are marked with **green**.

Machinery is marked with **blue**.

Materials are marked with **red**.

Units of work: These are the same as in Ford's budget, except for the **unit of work 2**, which is **not needed** in this budget, as **Fibro already has the original plans**.

1-Mounting/Dismounting: UW1.

UW1: Mounting/Dismounting					
Code	Unit	Description	Quantity	Price	Cost (€)
E01	h	Adjuster	18	46,01	828,18
E02	h	Assistant	18	46,01	828,18
M01	h	Adjuster's tools	18	8,28	149,04
M02	h	Assistant's tools	18	8,28	149,04
Total					1.954,44

2-Breakdown analysis: UW2.

UW2: Breakdown analysis					
Code	Unit	Description	Quantity	Price	Cost (€)
E03	h	Engineer	37,5	80,52	3.019,5
Total					3.019,5

3-Repair: UW3.

UW3: Repair					
Code	Unit	Description	Quantity	Price	Cost (€)
E01	h	Adjuster	30	46,01	1.380,3
E02	h	Assistant	30	46,01	1.380,3
M01	h	Adjuster's tools	30	8,28	248,4
M02	h	Assistant's tools	30	8,28	248,4
M04	Units	Spindle	1	2.684	2.684
M05	Units	Superior lid	1	1.306	1.306
M06	Units	Piston	1	3.042	3.042
M07	Units	Bearing	1	1.660	1.660
M08	Units	Antifriction sleeves	2	41,47	82,94
Total					12.032,34

4-Tests: UW4.

UW4: Tests					
Code	Unit	Description	Quantity	Price	Cost (€)
E01	h	Adjuster	18	46,01	828,18
E02	h	Assistant	18	46,01	828,18
M01	h	Adjuster's tools	18	8,28	149,04
M02	h	Assistant's tools	18	8,28	149,04
Total					1.954,44

Budget [23]:

Code	Description	Cost (€)
UW1	Mounting/Dismounting	1.954,44
UW2	Breakdown analysis	3.019,5
UW3	Repair	12.032,34
UW4	Tests	1.954,44
Total		18.960,72
Indirect costs (0,04 x Total)		758,43
Overhead (0,20 x Total)		3.792,14
Markup (0,06 x Total)		1.137,64
Inversion's budget		24.648,93

The total cost of the repair is:

Twenty-four thousand six hundred and forty-eight euros with ninety-three cents.

3.3. Savings

As we have seen, the repair performed by Ford has a cost of 17.711,34 €, 6.937,59 € less than Fibro's repair, that is 24.648,93 €. However, as we have said in the introduction of this chapter, **most companies reject any reparations when their price exceeds 50% of the new component's price**. In our case, the **indexing table costs 38.552,54 €**. Therefore, as the **cost of the repair is higher than 50%** of the initial price, we assume that **Fibro would refuse to perform any repair on the table**. Then, we should compare the price of the new table with Ford's repair. As a result:

Price of the indexing table: 38.552,54 €

Price of the repair: 17.711,34 €

Savings: 20.841,20 €

3.4. Etxe-tar's benefits

This **project is also exciting for Etxe-tar**, due to the **greater understanding of the internal mechanism** of the table that it offers. It could allow the company to **provide predictive maintenance** to prevent this kind of breakdowns, **improving the reliability** of the indexing tables and, consequently, **Etxe-tar's CNCs**. This fact would **improve the company image** in front of their clients, as it would improve efficiency in their production lines. An example of possible predictive maintenance could be the installation of accelerometers in the table. These elements will measure the vibrations of it when turning, an increment of vibrations would mean a deteriorating sign. This parameter would indicate the initiation of the deformation in the piston's surface, the initiation of the breakdown. This system would **guarantee enough time in advance to change the table before the total breakdown**. Avoiding significant repair and contributing to higher guarantees when modifying the table.

Consequently, we would **improve the maintainability and reliability** of the CNC. We must consider that when the total failure occurs, it usually involves a non-negligible time investment, as they imply the shipping of the component to the manufacturer's workshop. Therefore, the efficiency improvement is considerable if the company can prevent this kind of failures.

If we pay attention to the awards given by its clients, "efficiency award" by Ford, or "entrepreneurial performance" by Volkswagen, we can see that the commented benefits in the previous paragraphs concord perfectly with the aim of the company. To team up with its clients and create a long-term business relationship.

3.5. Conclusions

When we analyze both **budgets, Fibro's and Ford's**, we can see that there is a great **benefit for Ford**, as in this initial repair, the company was able to save **20.841,20 €**. However, this is just the first repair, where time investment is much more significant than the usual repair time. As a result, if Ford performs future repairs, Ford workers will be able to equalize time with Fibro, decreasing costs even more. Also, the unit of work 2, plans, will not be necessary for future operations. To summarize, **savings for Ford could substantially increase if continuing with this activity**. Nevertheless, the **main benefit is the major machine availability** due to the in-situ repair. This greater availability reduces extended production shutdowns, enabling the company to be more productive and efficient.

On the other hand, **Etxe-tar's benefits** are not as straight forward or tangible as Ford's. As we have seen, this project helps the company to have a **greater understanding of the mechanism** of the table. It enables the company to **prevent fatal failures** that would undoubtedly cause a significant inconvenience for its client. Therefore, this document will help the company to **build a sharper brand image, enhancing the reliability and maintainability** of its products, as Fibro tables are mounted in Etxe-tar's CNCs. This performance's increase will mean that clients' predisposition to purchase Etxe-tar's machinery will thrive. Contributing to the continuity of the company and its growing

Part 4

4 References

This brief part of the document aims to list all resources that have been used in this project. Whenever we used different chapters of the same source, the page number where the information is placed is also included in the reference.

The reference style used concurs with APA (American Psychological Association) guidelines. The appearance in the document orders references.

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[20] Matmatch. EN 1.7225. <https://matmatch.com/es/materials/minfm67283-astm-a193-grade-b7m-m100-and-under?filters%5B0%5D%5Btype%5D=text&filters%5B0%5D%5BfilterValue%5D=ASTM%20A193%20Grade%20B7M%20M100%20and%20under>

[21] *Processos de mecanitzat* [Power point slides]. Department of Mechanic and materials engineering, Universitat Politècnica de València (2019).

[22] *Metals i els seus aliatges* [Power point slides]. Department of Mechanic and materials engineering, Universitat Politècnica de València (2018).

[23] *Presupuesto cuadro de precios y pliego de condiciones*. Department of engineering projects, Universitat Politècnica de València.

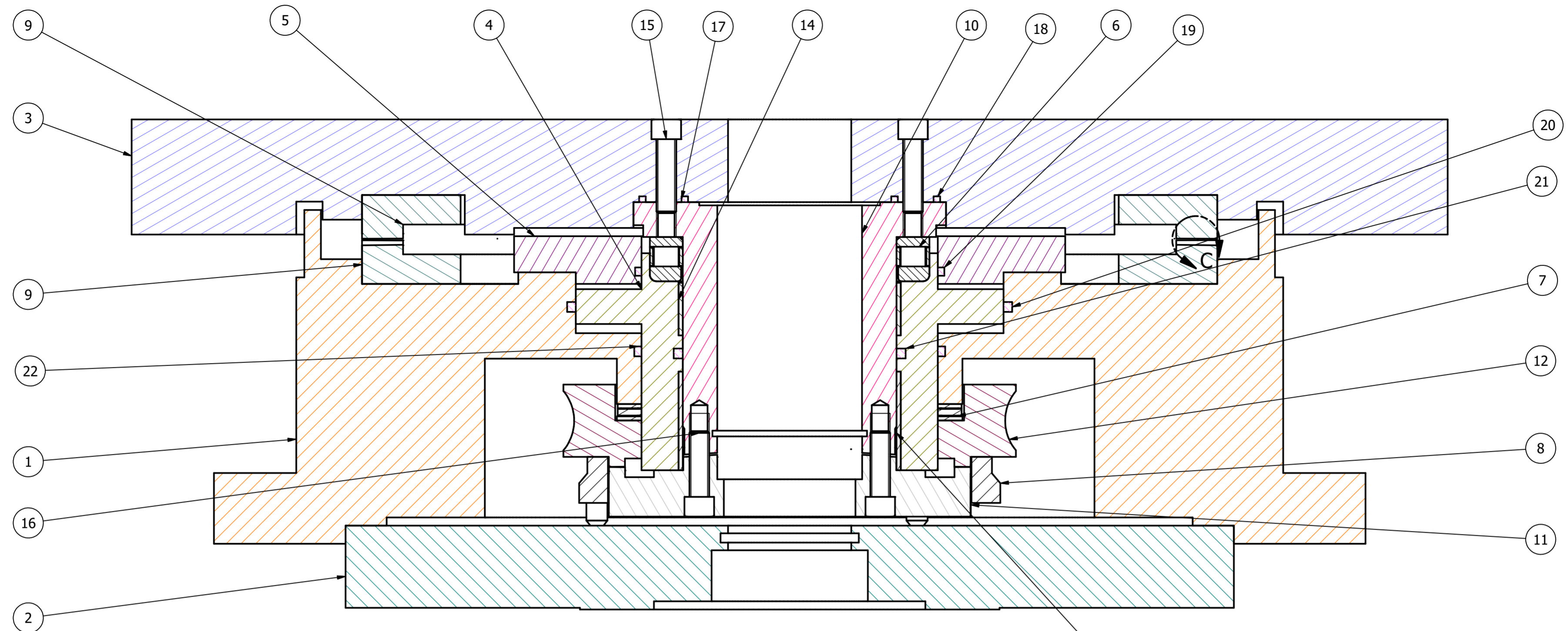
[24] *Toleràncies i acabats superficials*. Department of Graphic engineering, Universitat Politècnica de València.

Part 5

5 Plans

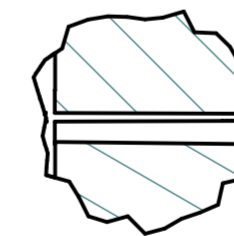
This part of the project **contains the plans of every component of the table that is not normalized**. This chapter aims to provide visual support of each part, enabling a greater understanding of the internal mechanism of the indexing table. We have also introduced an assembly plan in order to see the interaction between components. The **plans have been produced from the measures** that we made as we did not know the nominal measures of the components. Therefore, **all dimensions in the plans correspond to the measures performed in the workshop**. This point is essential since we were trying to replicate the behavior of our table. We could not have made this if we used nominal measures (in case we had them), due to the imprecision of manufacturing processes, that always have a tolerance margin.

Moreover, this part includes **plans of the original assembly and parts before the modifications**. Consequently, the **comparison between both mechanisms will be easier to perform**. To conclude this introduction, we must mention that every dimension has an associated tolerance according to the relative movement between components and ease of mounting/dismounting.



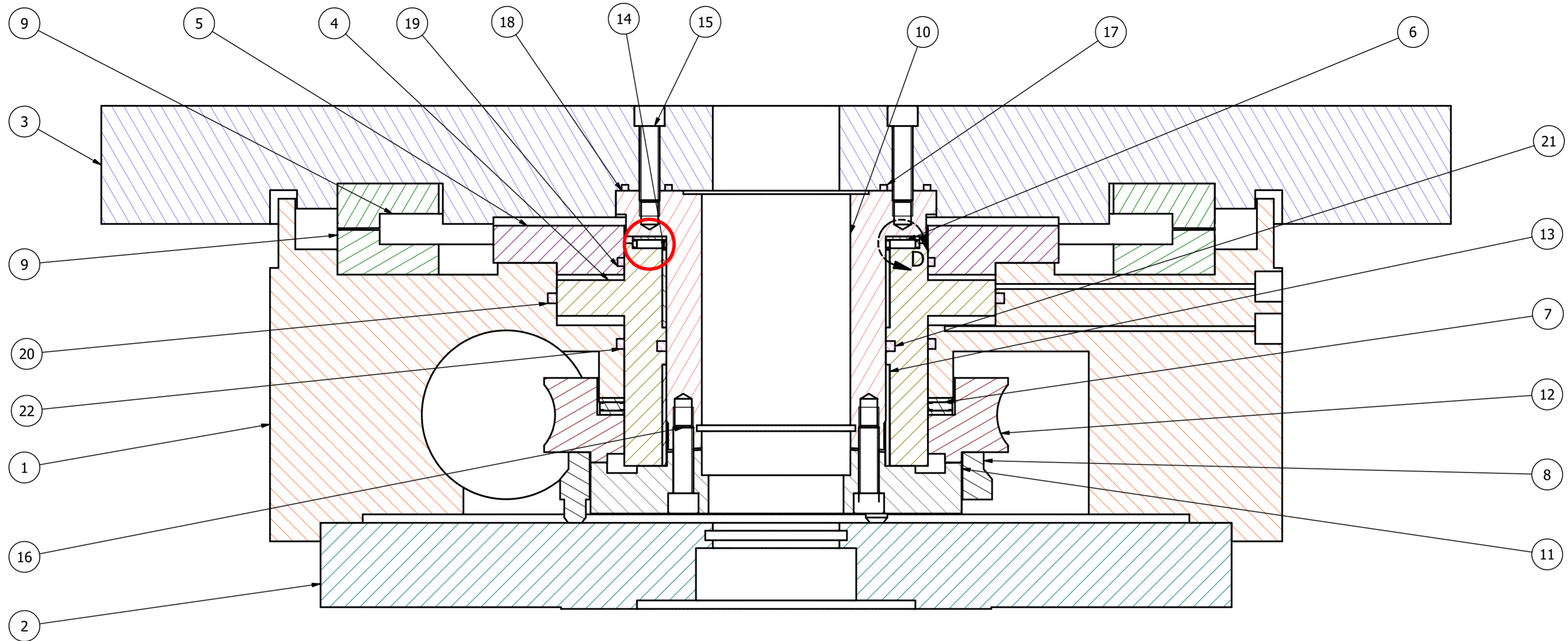
PARTS LIST			
ITEM	QTY	PART	DESCRIPTION
1	1	Base	Attachment to the machining center
2	1	Inferior lid	Attached to the base
3	1	Plate	Machining tools support
4	1	Piston	Lifting mechanism
5	1	Cilinder lid	Hydraulic chamber sealing
6	1	Roller bearing	Modified bearing
7	1	Needle bearing (crown)	OK
8	1	Crown support	Not fixed
9	2	360° teeth	Precision gear
10	1	Spindle	Rotating mechanism
11	1	Clutch	Movement transmitter
12	1	Crown	Worm-screw component
13	1	Anti-friction sleeve	Allows relative movement between spindle and piston
14	1	Upper anti-friction sleeve	Allows relative movement between spindle and piston
15	4	M12 x 45-12.9	ISO metric hexagon socket head cap screws
16	4	M12 x 40-12.9	ISO metric hexagon socket head cap screws
17	1	O-ring sealing 123,19x5,33	Impeeds entry of machining shavings
18	1	O-ring sealing 175x5,3	Impeeds entry of machining shavings
19	1	Quadring sealing 177,17x5,33	Upper hydraulic chamber sealing
20	1	Quadring sealin 253,37x6,99	Chamber's separation
21	1	Quadring sealing 129,54x6,99	Piston-spindle sealing
22	1	Quadring sealing 177,17x6,99	Inferior hydraulic chamber sealing

Anotation 1: 13 and 14 correspond to a three layer anti-friction sleeves type. This layers are made of steel, bronze and polytetrafluorethylene with inert aditives (E40). This kind of anti-friction components are designed to work with no lurication

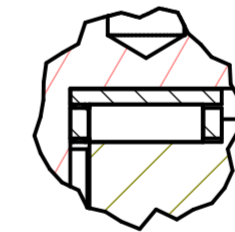


DETAIL C
SCALE 1 : 1

Anotation 2: This gear correspond to a Hirth coupling. Every gear in the indexing table except the wormscrew have Hirth teeth. This enables great positioning precision and torque transmition.



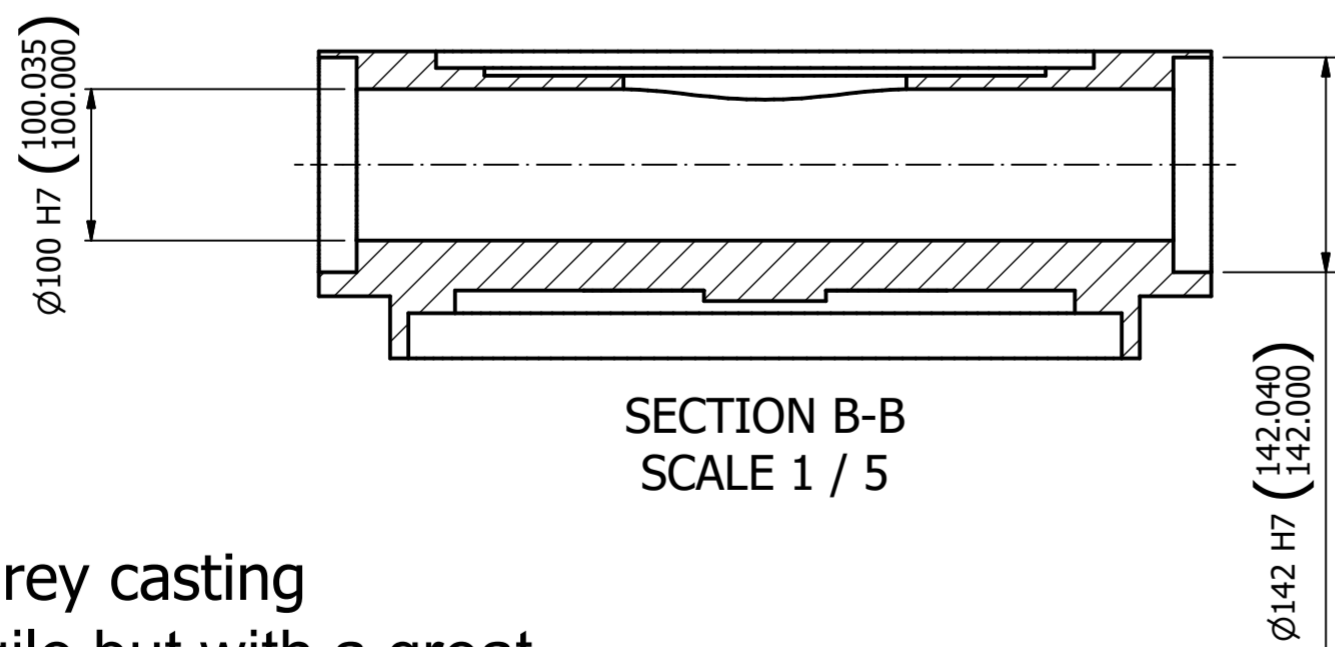
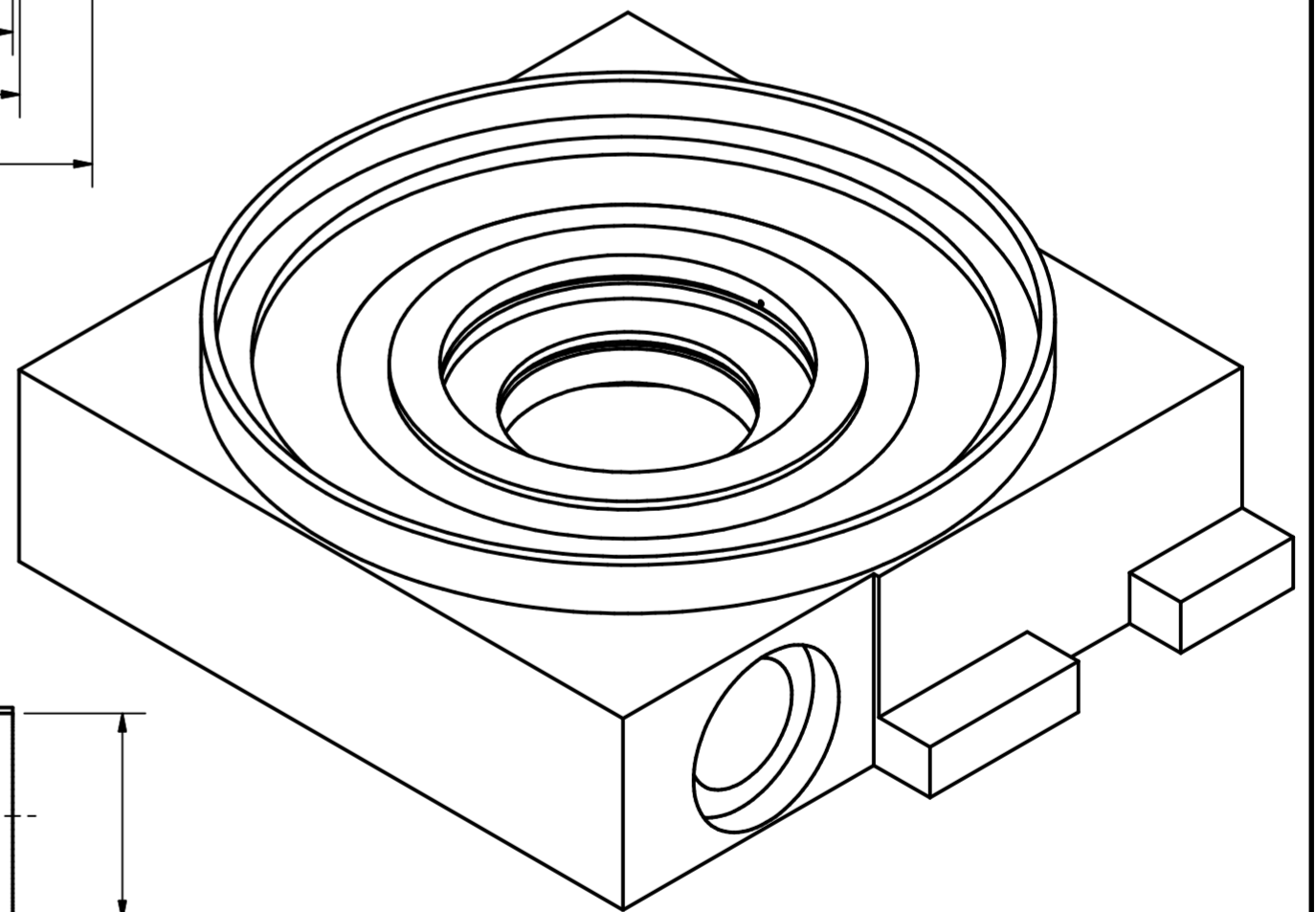
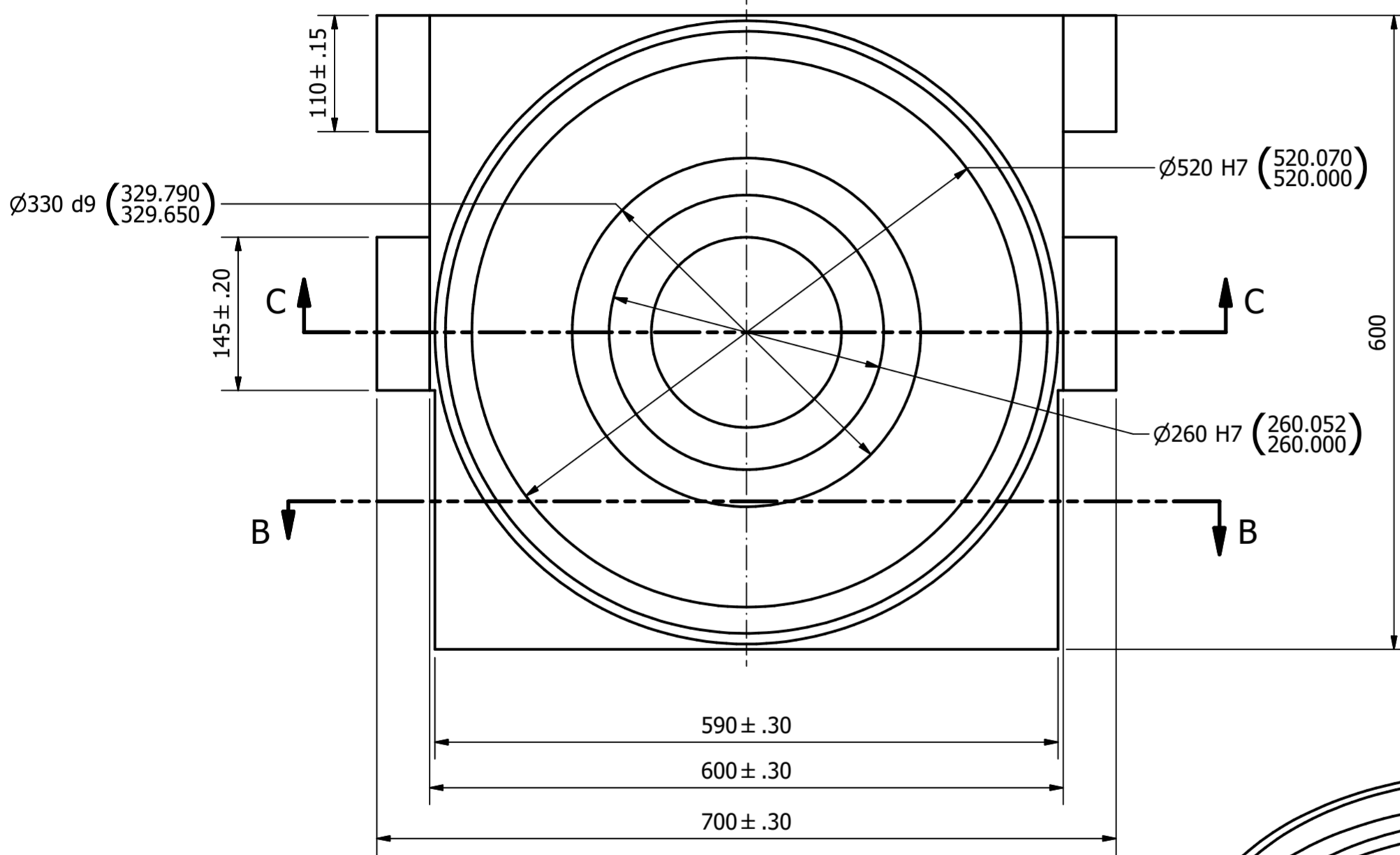
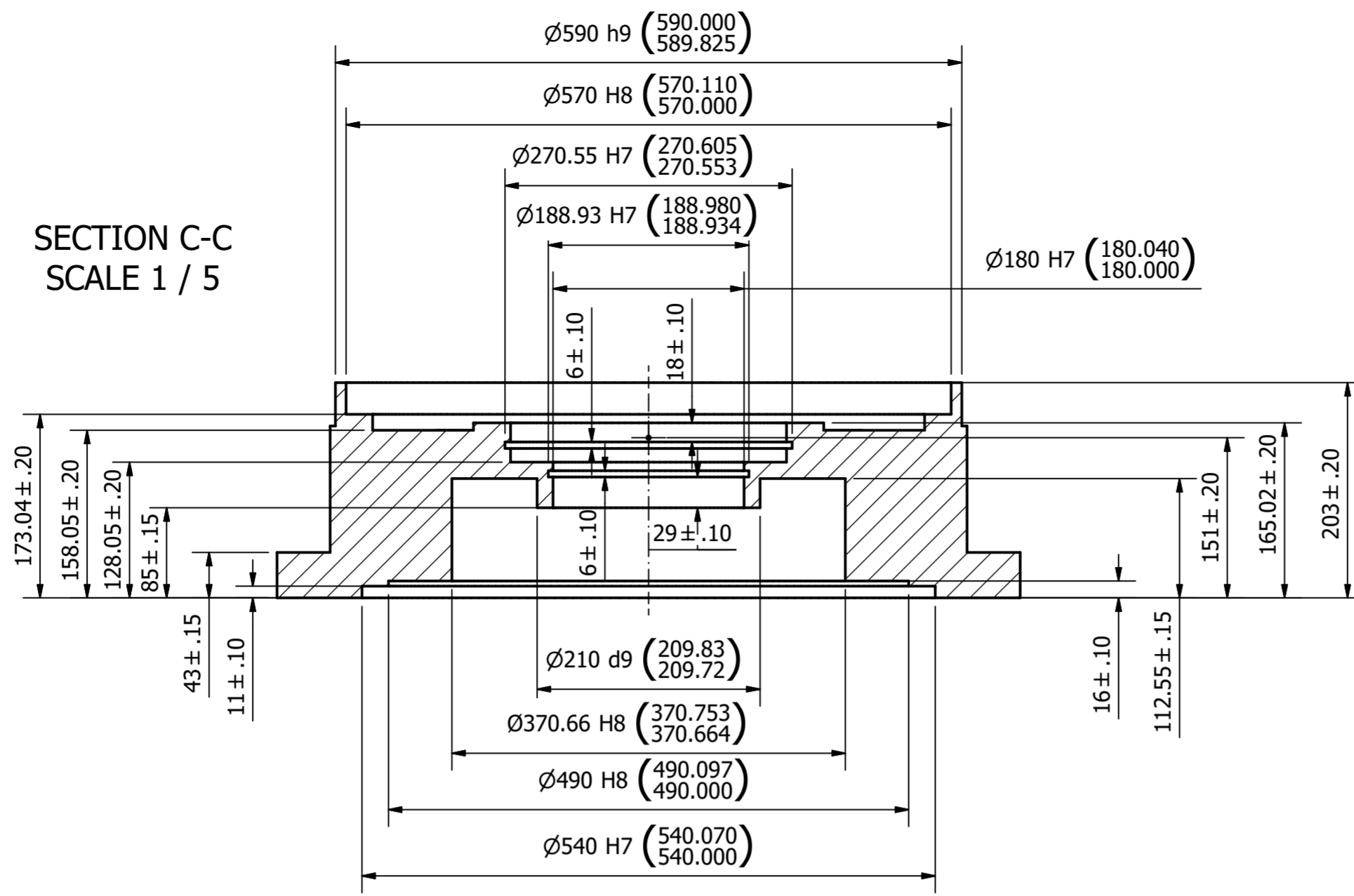
PARTS LIST			
ITEM	QTY	PART	DESCRIPTION
1	1	Base	Attachment to the machining center
2	1	Inferior lid	Attached to the base
3	1	Plate	Machining tools support
4	1	Piston	Lifting mechanism
5	1	Cilinder lid	Hydraulic chamber sealing
6	1	Needle bearing	Broken bearing
7	1	Needle bearing (crown)	OK
8	1	Crown support	Not fixed
9	2	360° teeth	Precision gear
10	1	Spindle	Rotating mechanism
11	1	Clutch	Movement transmitter
12	1	Crown gear	Worm-screw component
13	1	Anti-friction sleeve	Allows relative movement between spindle and piston
14	1	Upper anti-friction sleeve	Allows relative movement between spindle and piston
15	4	M12 x 45-12.9	ISO metric hexagon socket head cap screws
16	4	M12 x 40-12.9	ISO metric hexagon socket head cap screws
17	1	O-ring sealing 123,19x5,33	Impeeds entry of machining shavings
18	1	O-ring sealing 175x5,3	Impeeds entry of machining shavings
19	1	Quadring sealing 177,17x5,33	Upper hydraulic chamber sealing
20	1	Quadring sealing 253,37x6,99	Chamber's separation
21	1	Quadring sealing 129,54x6,99	Piston-spindle sealing
22	1	Quadring sealing 177,17x6,99	Inferior hydraulic chamber sealing



DETAIL D
SCALE 1 : 1

The inferior rolling surface of the bearing was not mounted in the original design. The surface of the piston is in contact with the rolling elements. This is the cause of the breakdown.

SECTION C-C
SCALE 1 / 5



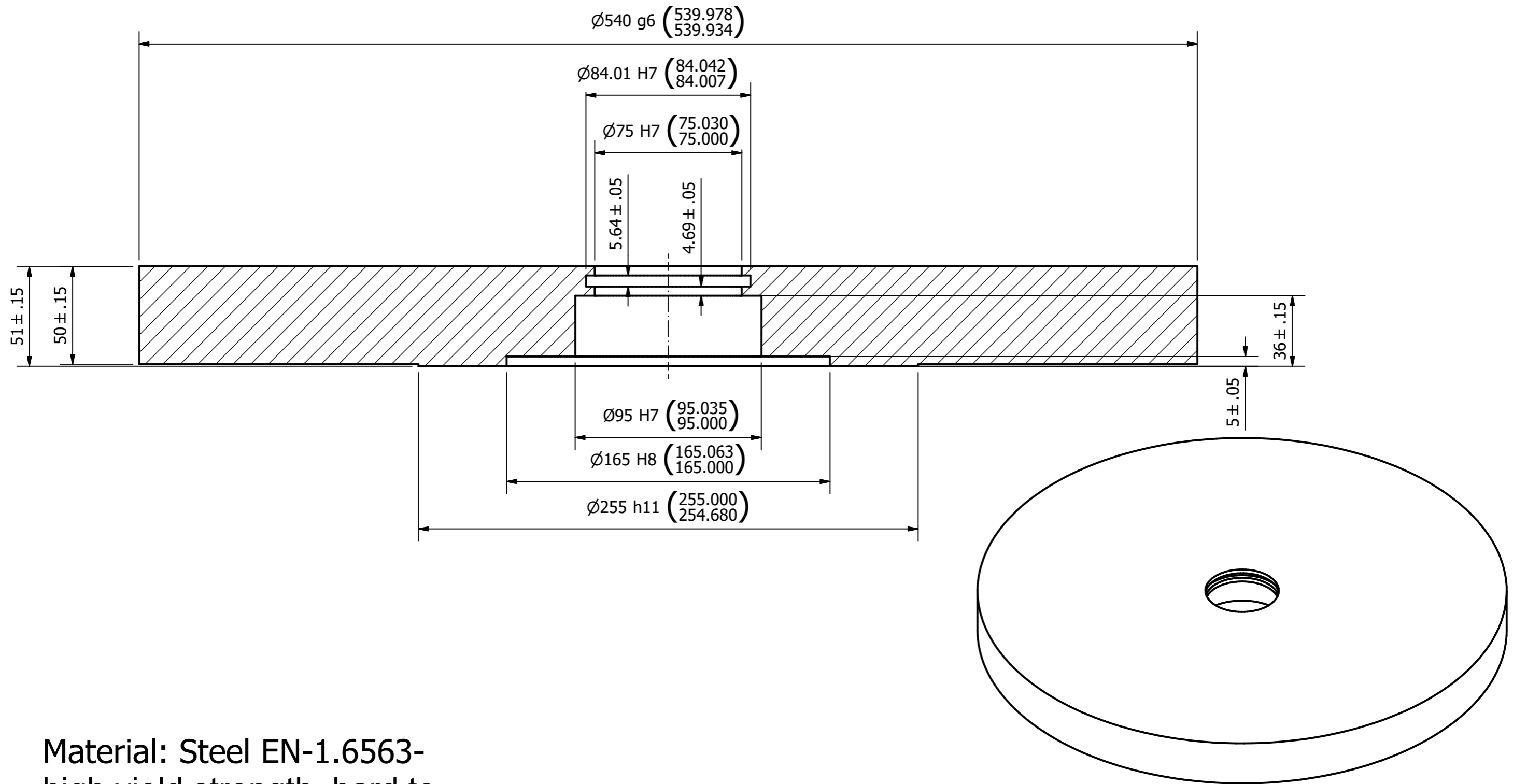
SECTION B-B
SCALE 1 / 5

Material: Grey casting
G3500-fragile but with a great
resistance to wear and capable of
mitigate vibrations

Tolerances according to ISO 2768 f


Linear dimensions	<6	>6-30	>30-120	>120-400	>400-1000	>1000-2000	>2000
Tolerances	±0,05	±0,1	±0,15	±0,2	±0,3	±0,5	

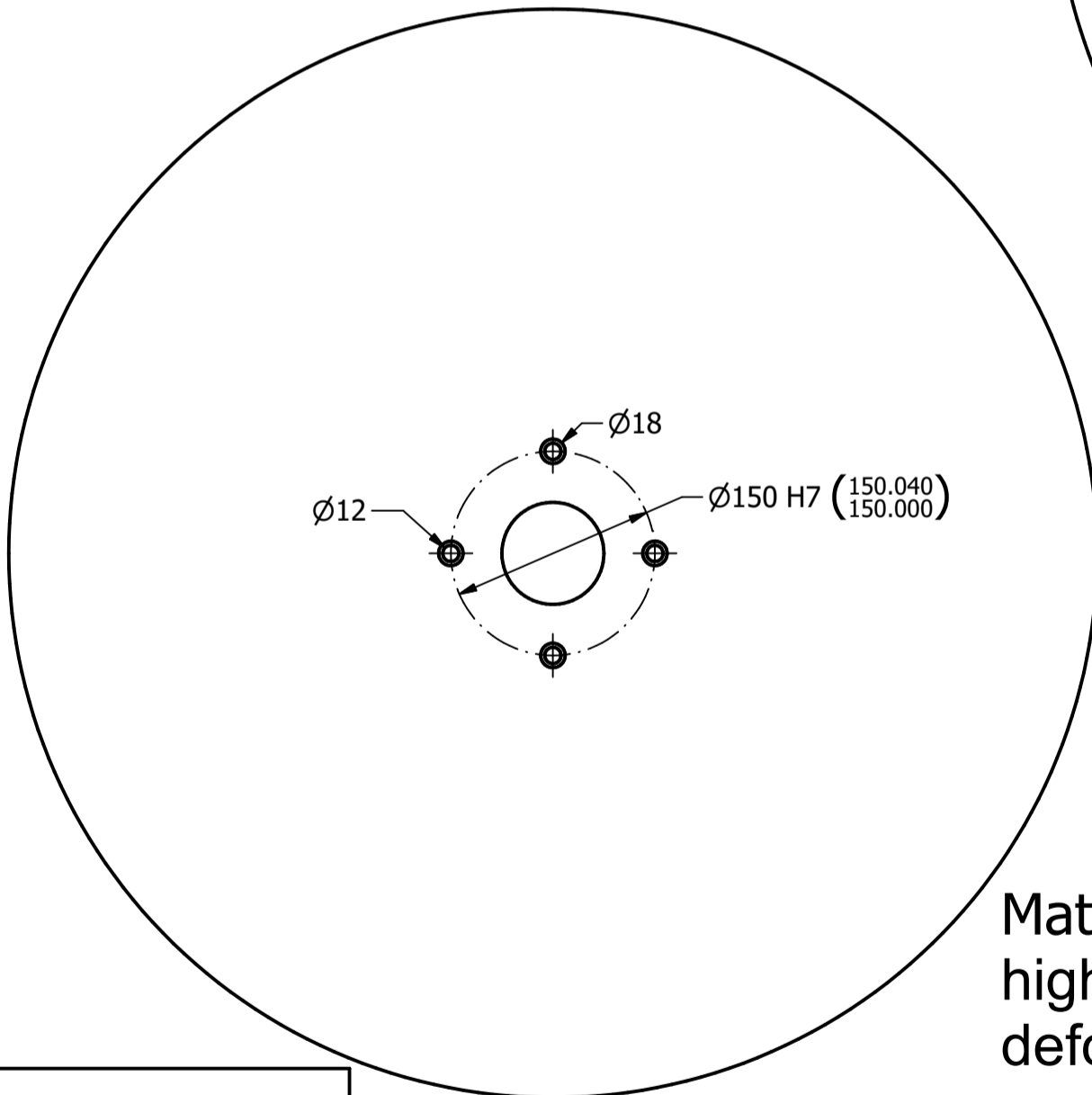
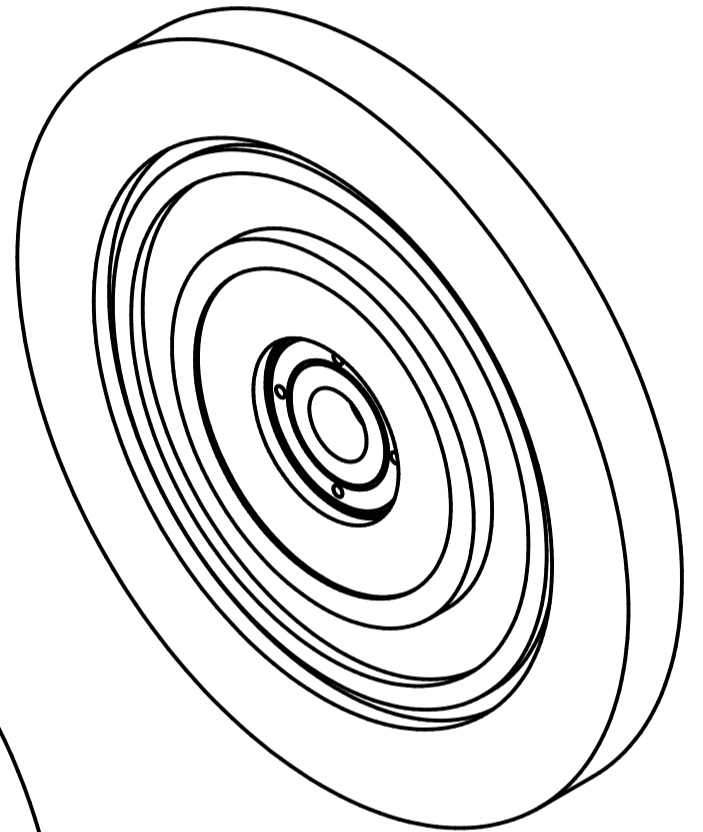
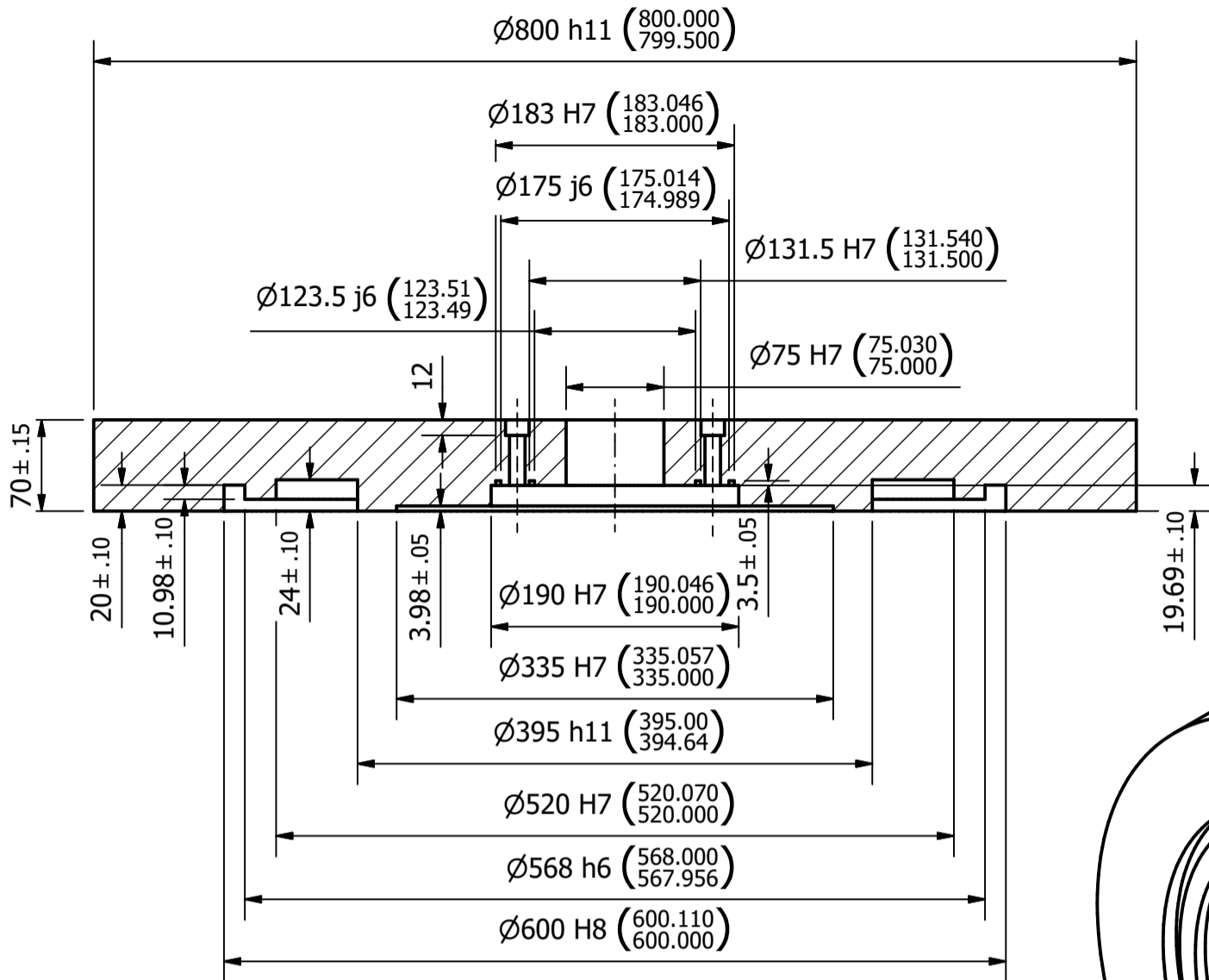
Industrial technologies engineering final project		Project	
UNIVERSITAT POLITÈCNICA DE VALÈNCIA		Analysis, diagnosis and redesign of an indexing table incorporated in a camshaft production line.	
ESCOLA TÈCNICA SUPERIOR ENGINYERIA INDUSTRIAL VALÈNCIA		Date	Scale
Author		15/04/2020	1:5
Initiated by Ernesto Colomer Torres (Ford employee). Developed and Completed by Llac Hernández Linares (Author of the project).		Title	Sheet
		Base	1



Material: Steel EN-1.6563-
high yield strength, hard to
deform, good machinability.

Tolerances according to ISO 2768 f							
Linear dimensions	<6	>6-30	>30-120	>120-400	>400-1000	>1000-2000	>2000
Tolerances	±0,05	±0,1	±0,15	±0,2	±0,3	±0,5	


Industrial technologies engineering final project  UNIVERSITAT POLITÈCNICA DE VALÈNCIA ESCOLA TÈCNICA SUPERIOR ENGINYERIA INDUSTRIAL VALÈNCIA		Project Analysis, diagnosis and redesign of an indexing table incorporated in a camshaft production line.	
Author Initiated by Ernesto Colomer Torres (Ford employee). Developed and Completed by Llac Hernández Llinares (Author of the project).		Date 15/04/2020	Scale 1:2
		Title Inferior lid	Sheet 2

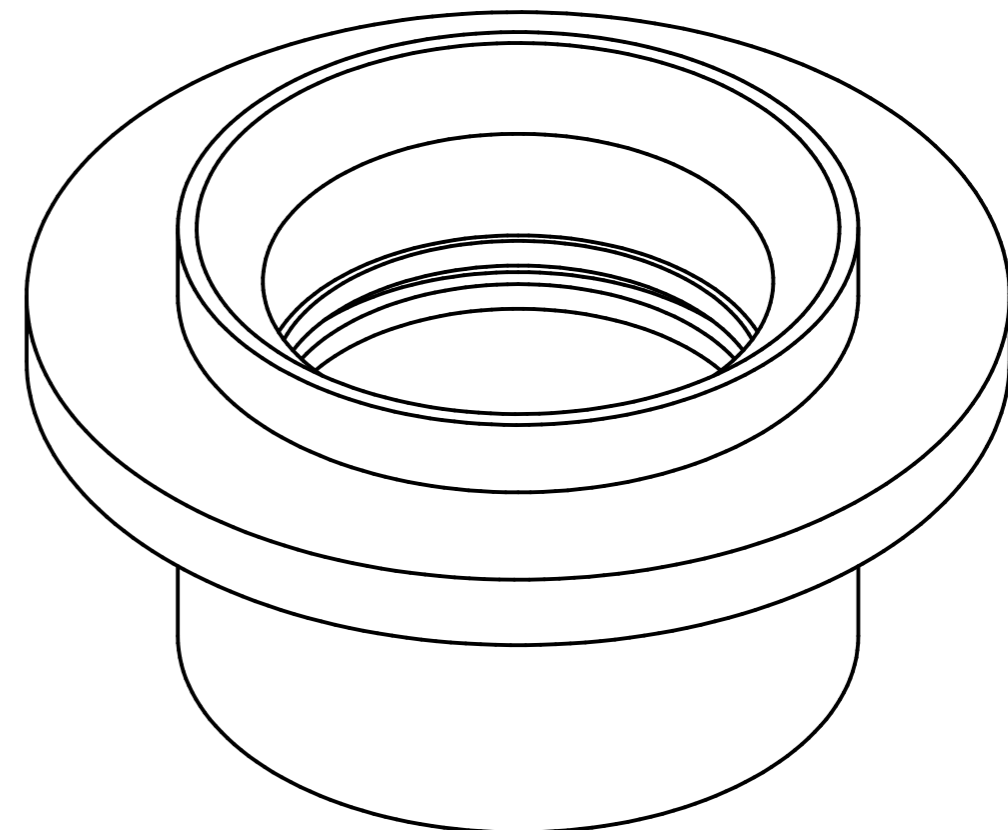
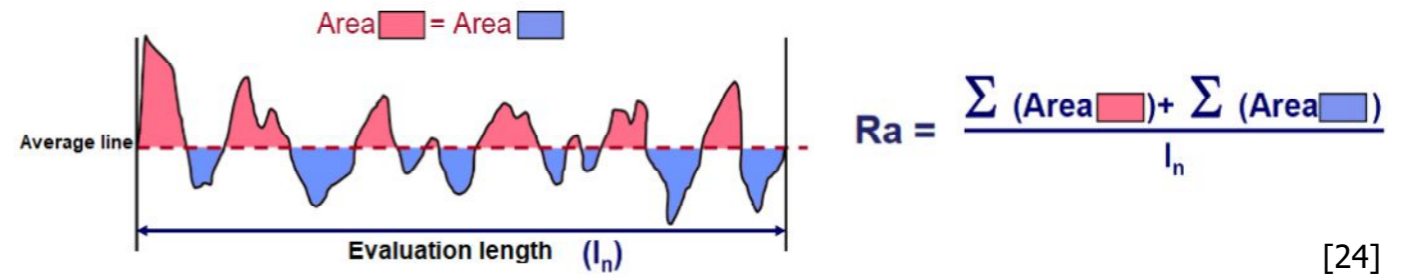
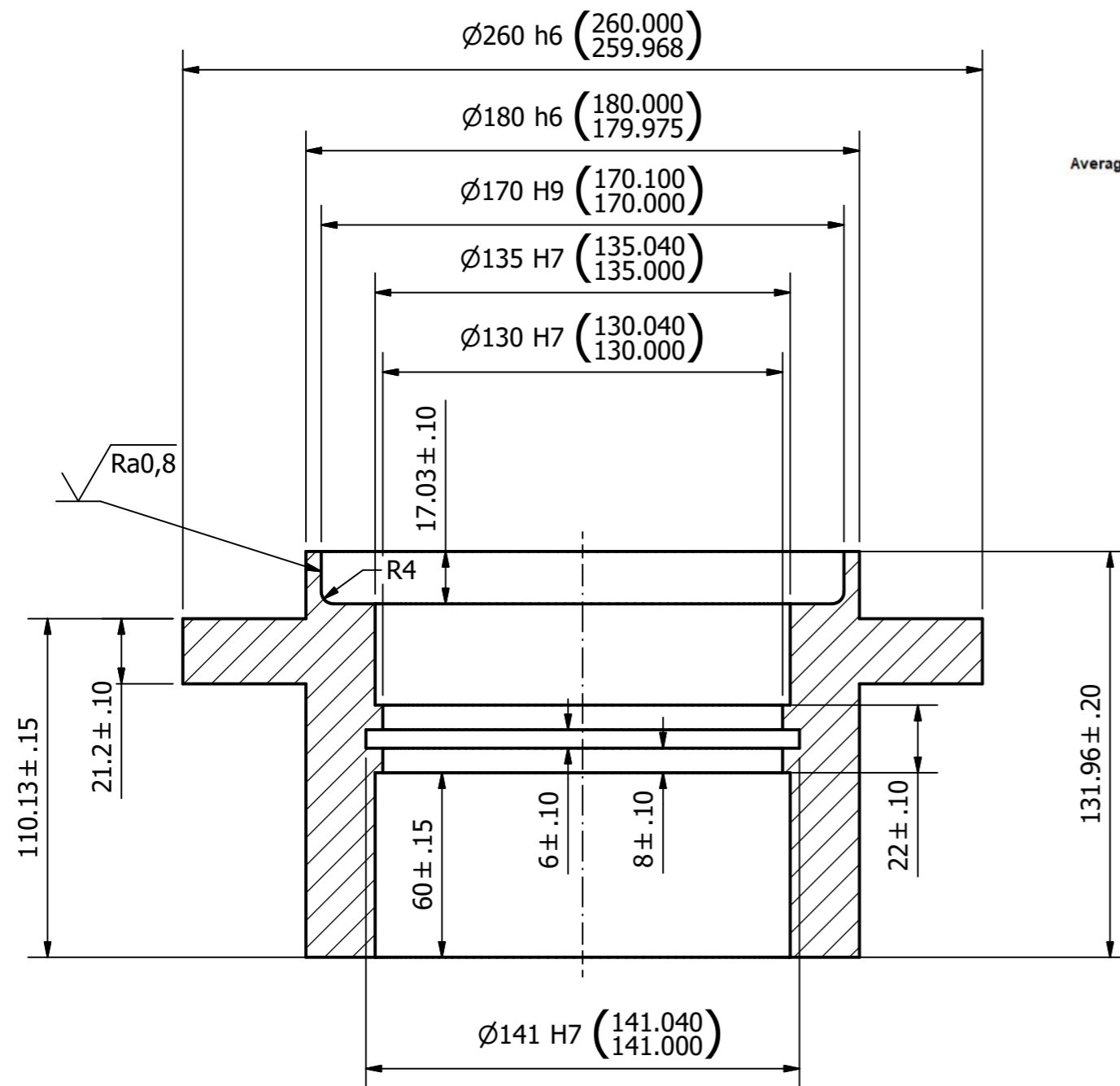


Material: Steel EN 1.6563-
high yield strength, hard to
deform, good
machinability.

Tolerances according to ISO 2768 f

Linear dimensions	<6	>6-30	>30-120	>120-400	>400-1000	>1000-2000	>2000
Tolerances	±0,05	±0,1	±0,15	±0,2	±0,3	±0,5	

Industrial technologies engineering final project 	Project	Title	Date	Sheet
	Analysis, diagnosis and redesign of an indexing table incorporated in a camshaft production line.	Plate	15/04/2020	3
		Author Initiated by Ernesto Colomer Torres (Ford Employee) Developed and completed by Llac Hernández Llinares (Author of the project)	Scale	1:5

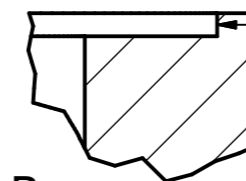
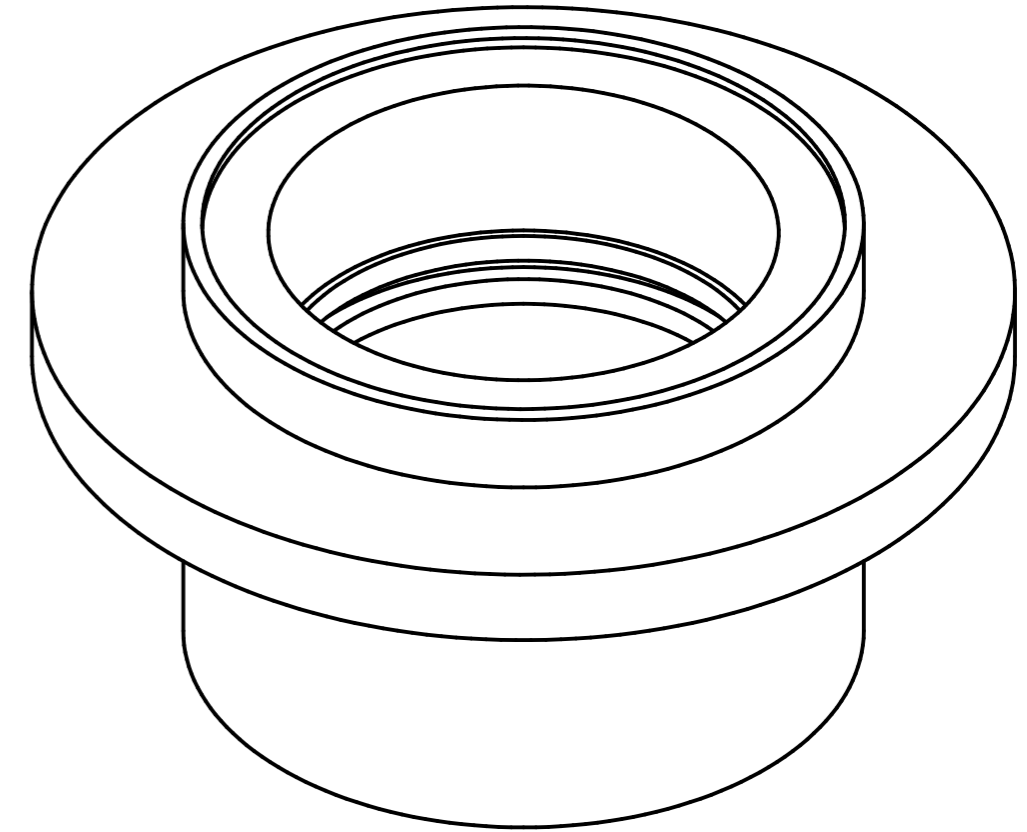
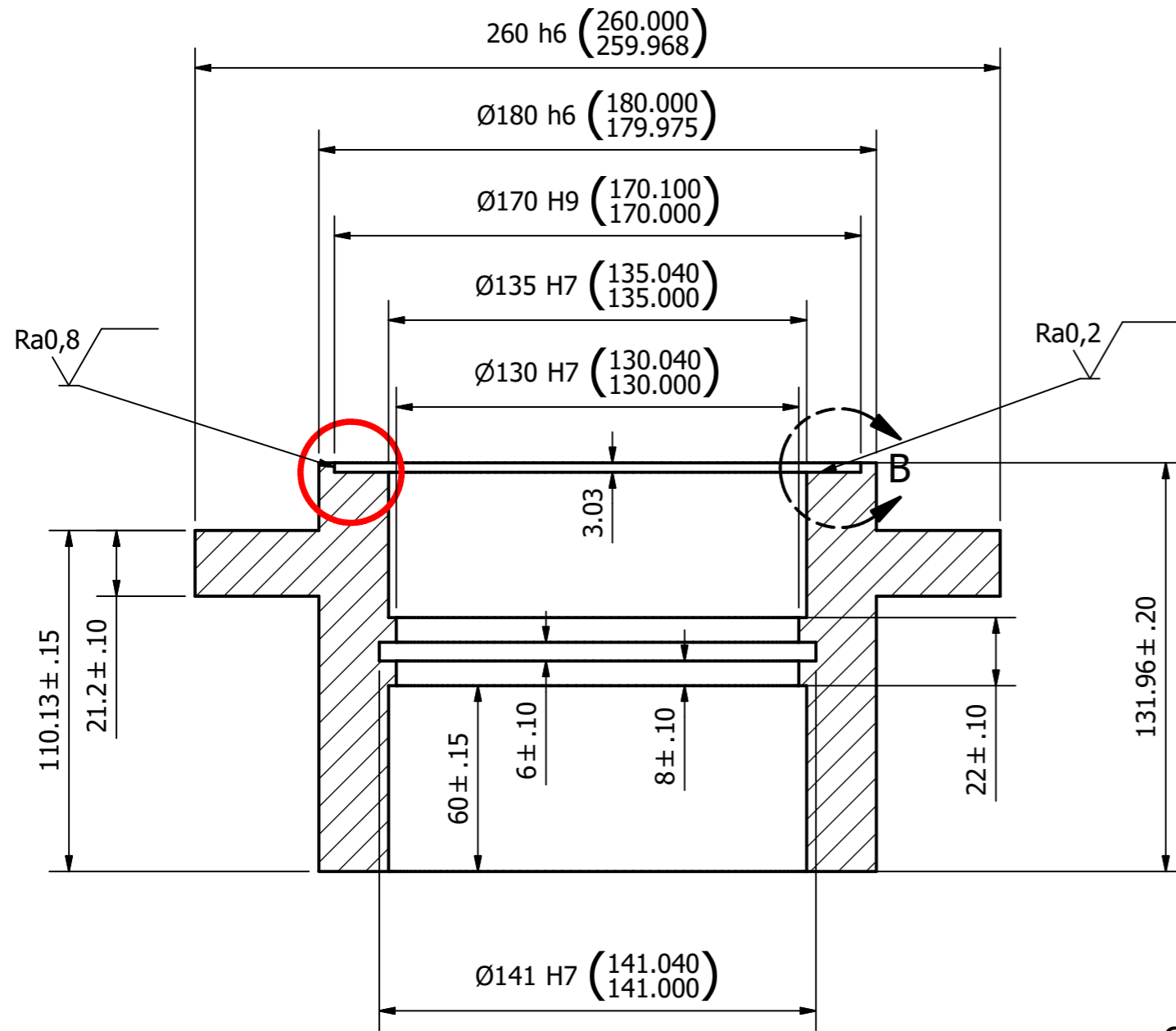
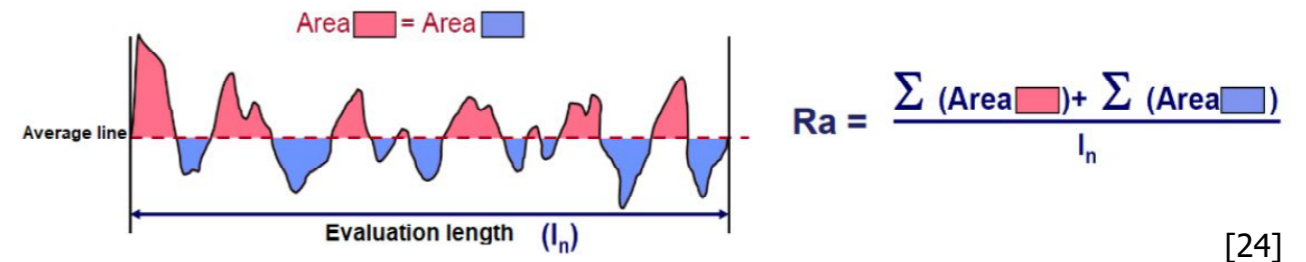


Material: Steel EN 1.4057- good wear resistance and it is highly polishable

Tolerances according to ISO 2768 f

Linear dimensions	<6	>6-30	>30-120	>120-400	>400-1000	>1000-2000	>2000
Tolerances	±0,05	±0,1	±0,15	±0,2	±0,3	±0,5	

Industrial technologies engineering final project		Project	
UNIVERSITAT POLITÈCNICA DE VALÈNCIA		Analysis, diagnosis and redesign of an indexing table incorporated in a camshaft production line.	
ESCOLA TÈCNICA SUPERIOR ENGINYERIA INDUSTRIAL VALÈNCIA		Date	Scale
Author		15/04/2020	1:2
Initiated by Ernesto Colomer Torres (Ford employee). Developed and Completed by Llac Hernández Llinares (Author of the project).		Title	Sheet
		Piston	4



This depth has been increased to house a wider bearing with both rolling surfaces.

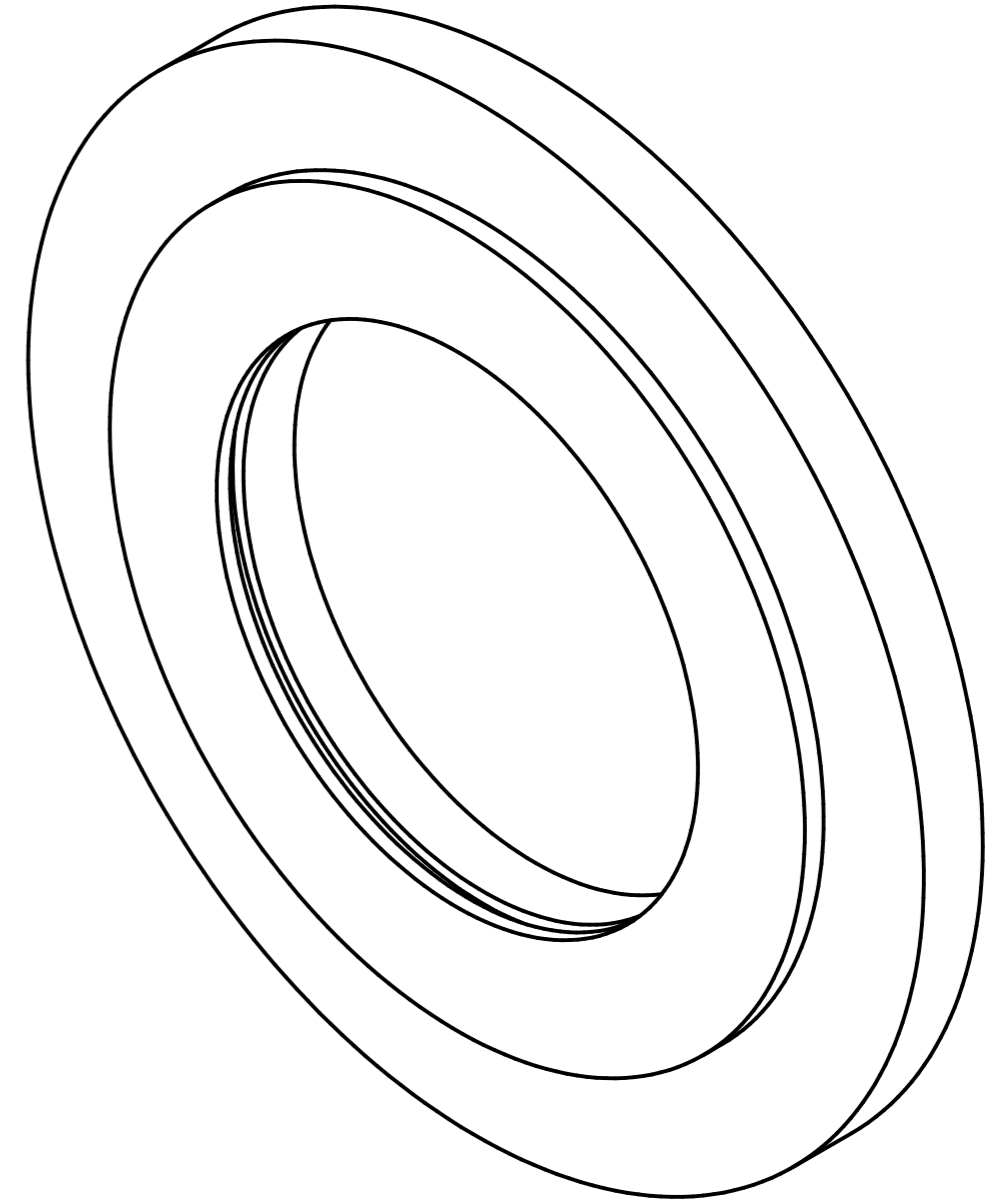
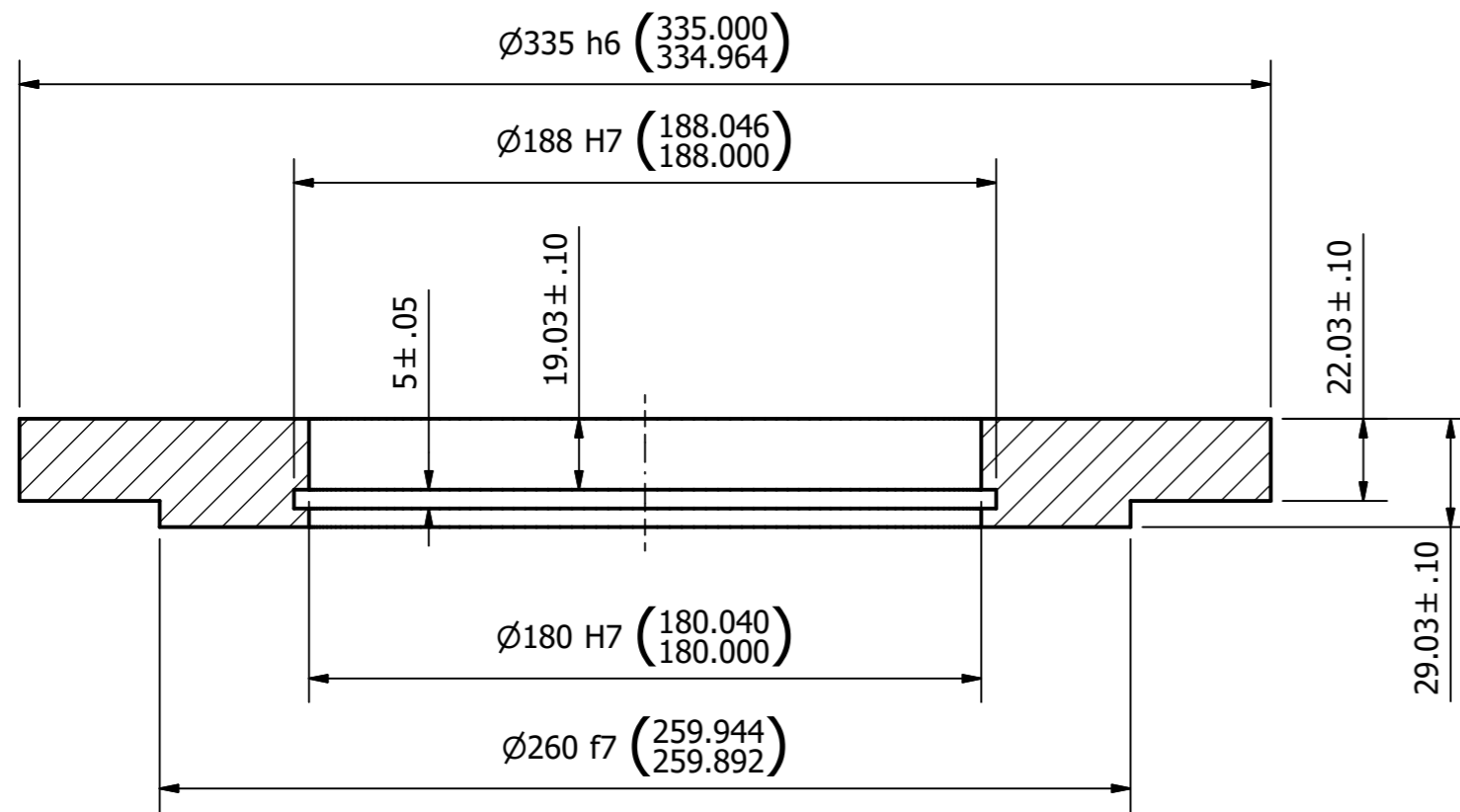
DETAIL B
SCALE 1 : 1

Material: Steel EN 1.4057- good wear resistance and it is highly polishable

Tolerances according to ISO 2768 f

Linear dimensions	<6	>6-30	>30-120	>120-400	>400-1000	>1000-2000	>2000
Tolerances	±0,05	±0,1	±0,15	±0,2	±0,3	±0,5	


Industrial technologies engineering final project		Project	
UNIVERSITAT POLITÈCNICA DE VALÈNCIA		Analysis, diagnosis and redesign of an indexing table incorporated in a camshaft production line.	
ESCOLA TÈCNICA SUPERIOR ENGINYERIA INDUSTRIAL VALÈNCIA		Date	Scale
Author		15/04/2020	1:2
Initiated by Ernesto Colomer Torres (Ford employee). Developed and Completed by Llac Hernández Llinares (Author of the project).		Title	Sheet
		Orginial piston	4.1



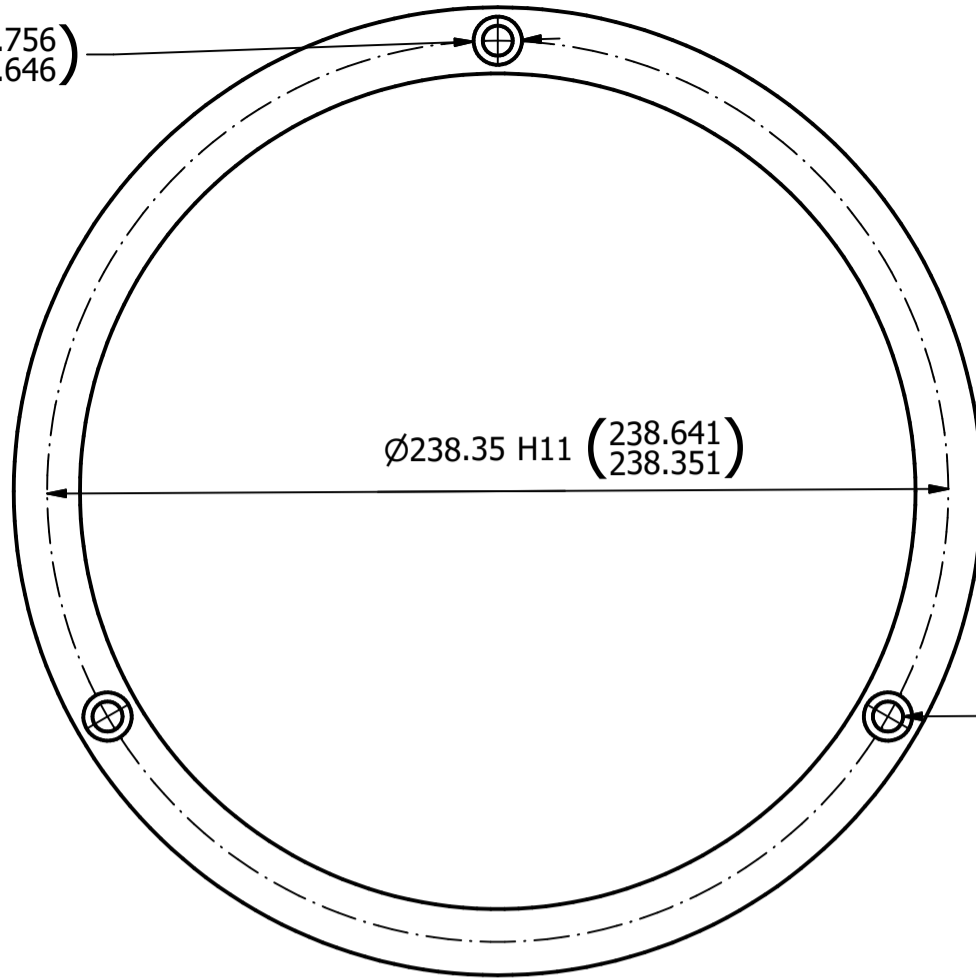
Material: Steel EN-1.6563- high yield strength, hard to deform, good machinability.

Tolerances according to ISO 2768 f

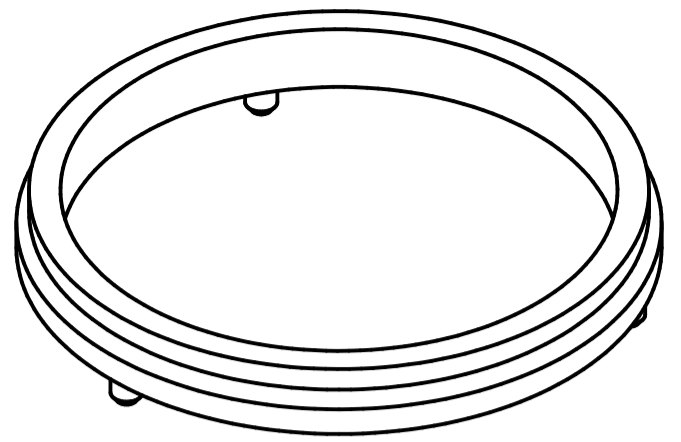
Linear dimensions	<6	>6-30	>30-120	>120-400	>400-1000	>1000-2000	>2000
Tolerances	±0,05	±0,1	±0,15	±0,2	±0,3	±0,5	

Industrial technologies engineering final project		Project	
		Analysis, diagnosis and redesign of an indexing table incorporated in a camshaft production line.	
Author		Date	Scale
Initiated by Ernesto Colomer Torres (Ford employee). Developed and Completed by Llac Hernández Llinares (Author of the project).		15/04/2020	1:2
		Title	Sheet
		Cylinder lid	5

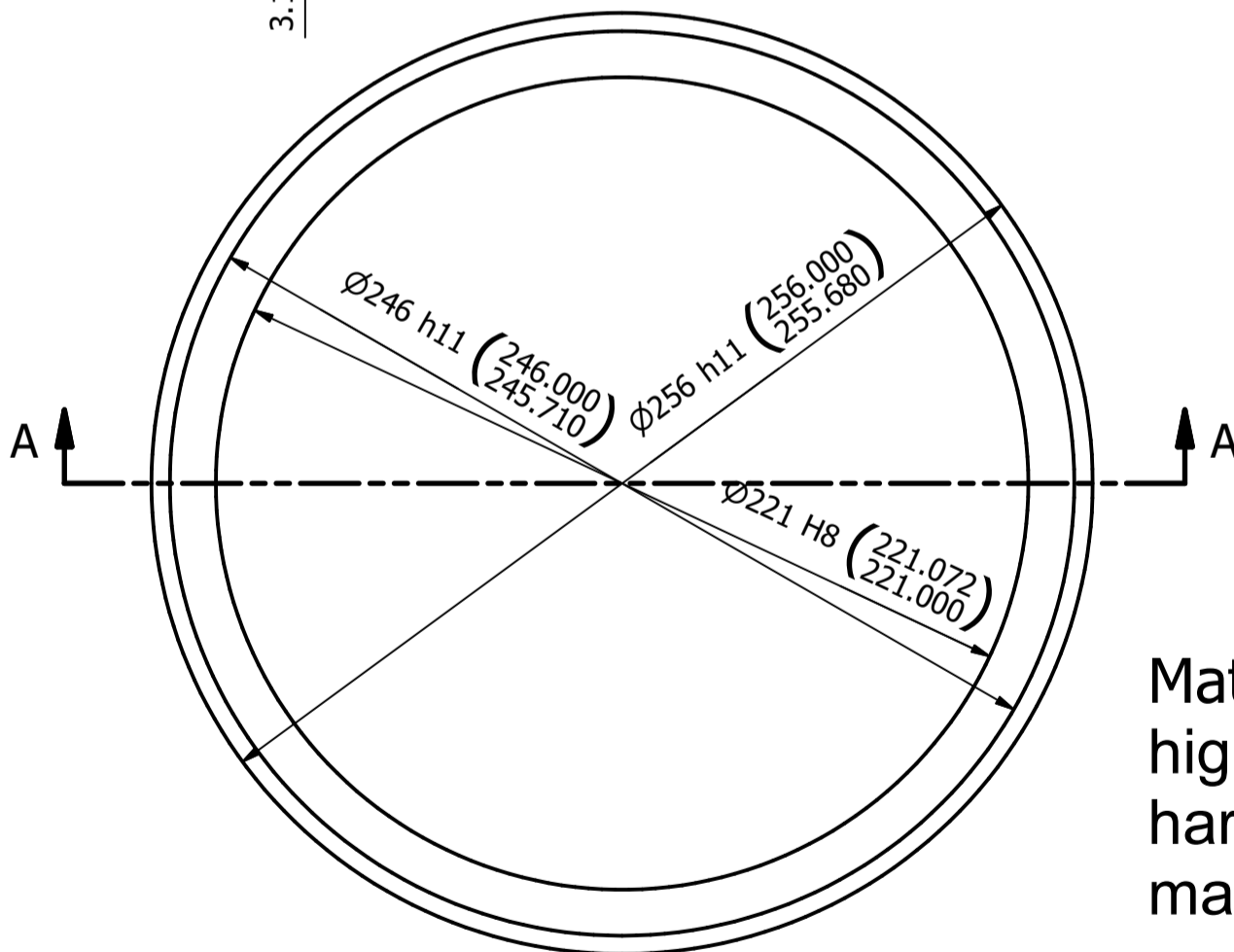
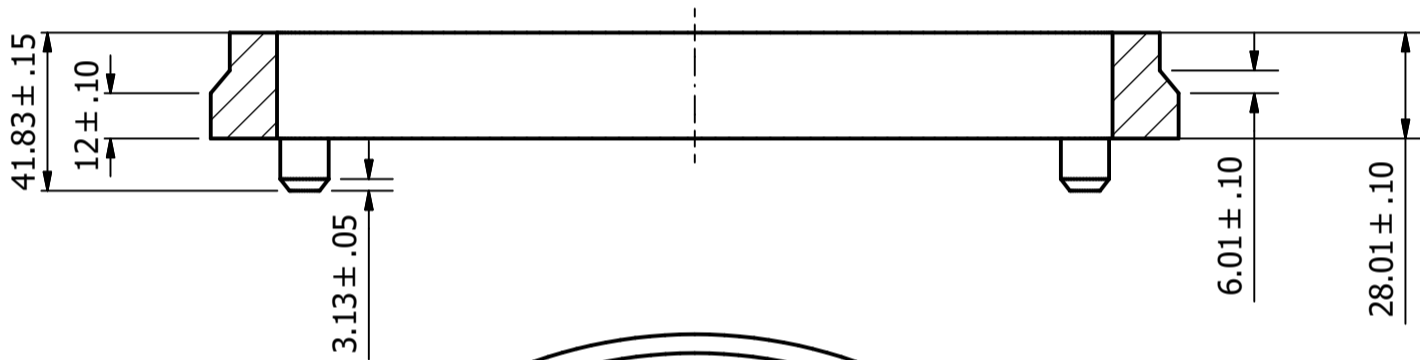
Ø12.79 e11 (12.756 / 12.646)



Ø238.35 H11 (238.641 / 238.351)




Ø7.96 e11 (7.932 / 7.842)

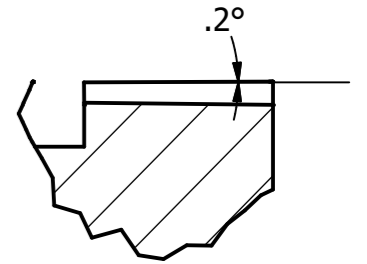
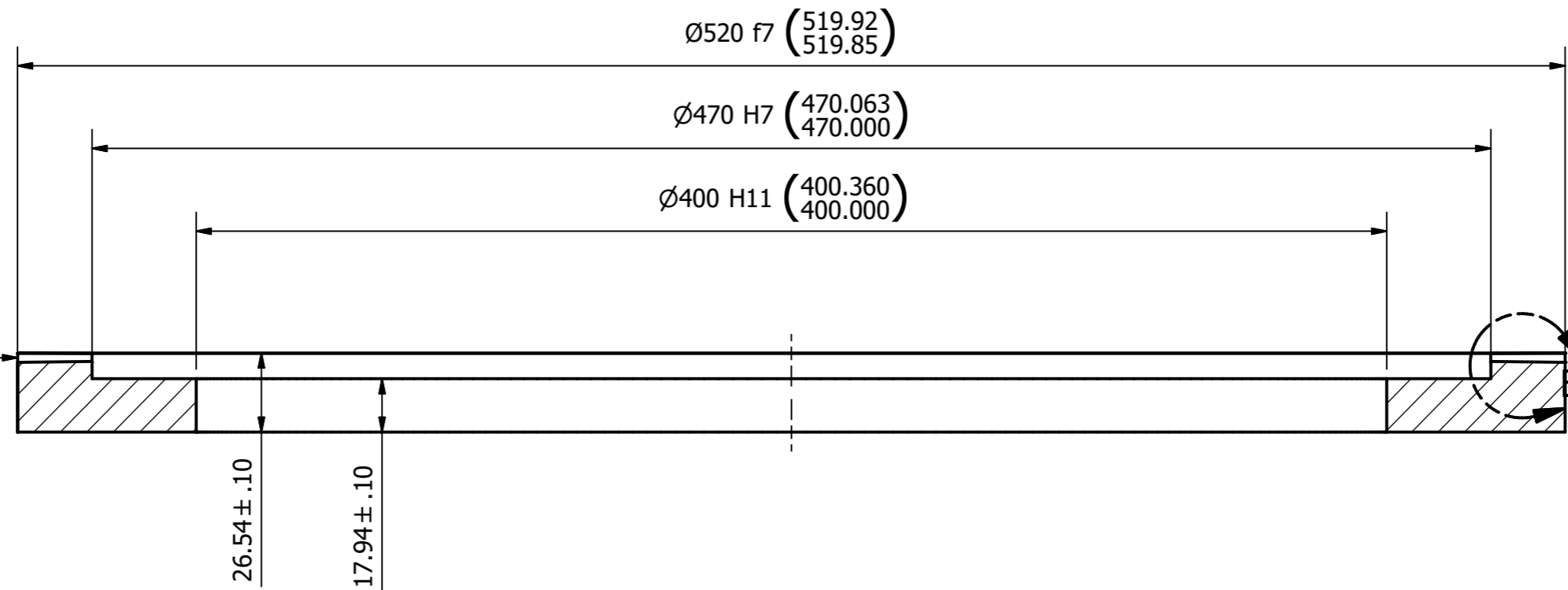
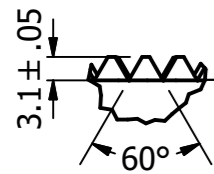


Material: Steel 1.6563-
high yield strength,
hard to deform, good
machinability.

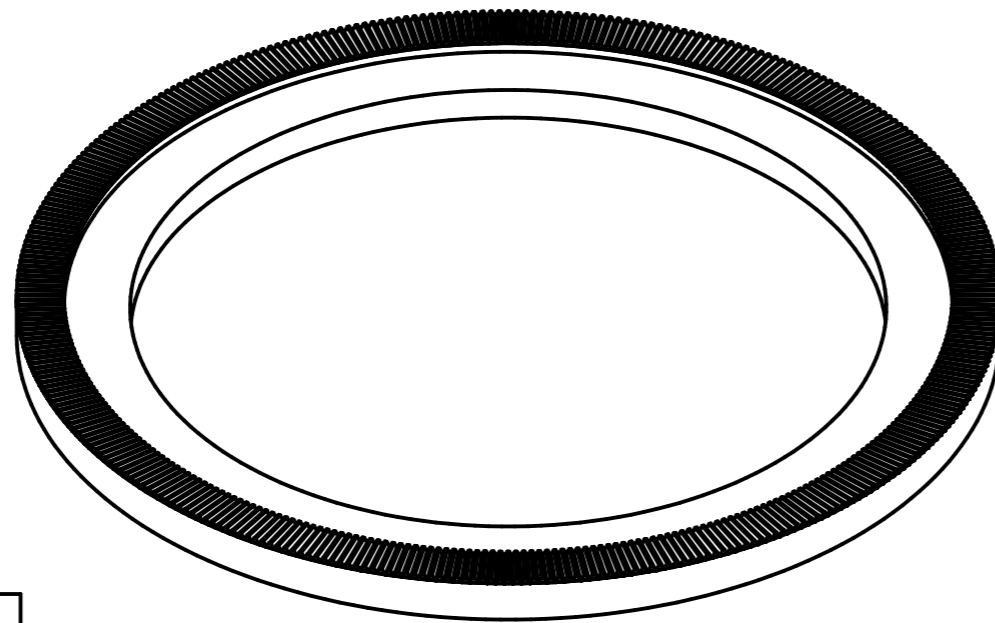
Tolerances according to ISO 2768 f

Linear dimensions	<6	>6-30	>30-120	>120-400	>400-1000	>1000-2000	>2000
Tolerances	±0,05	±0,1	±0,15	±0,2	±0,3	±0,5	

Industrial technologies engineering final project 	Project	Title	Date	Sheet
	Analysis, diagnosis and redesign of an indexing table incorporated in a camshaft production line.	Crown gear support		8
		Author Initiated by Ernesto Colomer Torres (Ford Employee) Developed and completed by Llac Hernández Llinares (Author of the project)	Date 15/04/2020	Scale 1:2



DETAIL B
SCALE 1 : 1



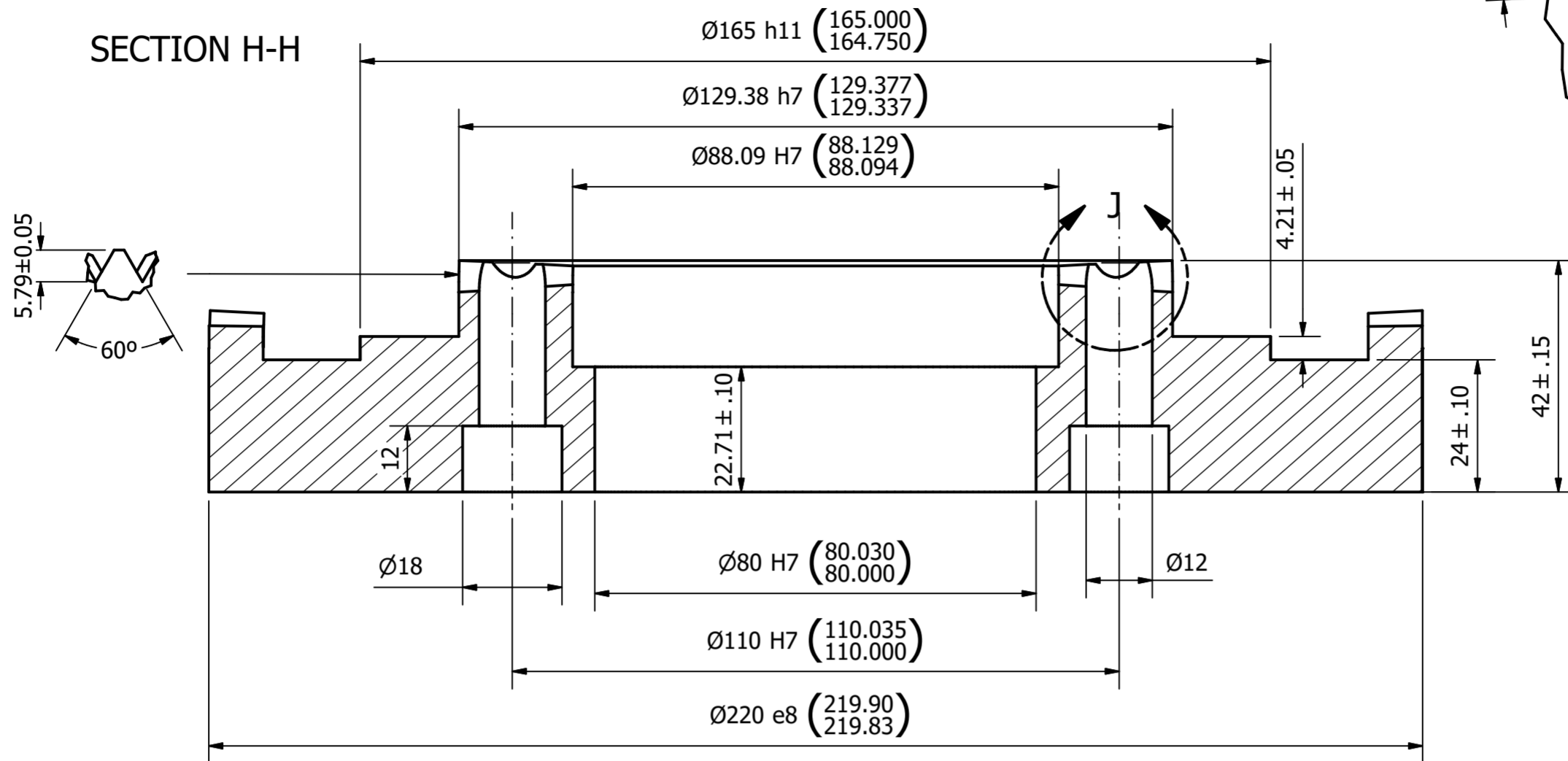
Material: Steel EN 1.7225-
great resistance and good
toughness

Tolerances according to ISO 2768 f

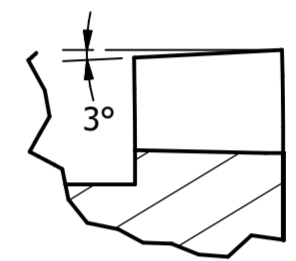
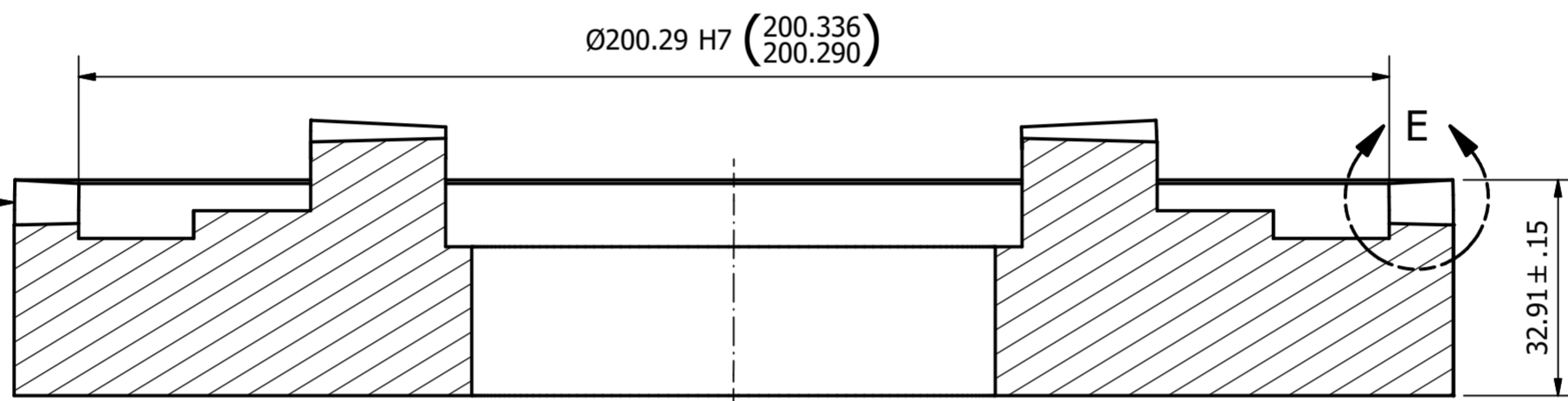
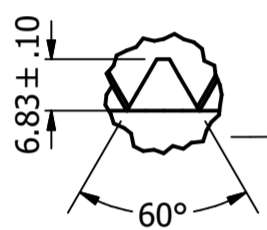
Linear dimensions	<6	>6-30	>30-120	>120-400	>400-1000	>1000-2000	>2000
Tolerances	±0,05	±0,1	±0,15	±0,2	±0,3	±0,5	

Industrial technologies engineering final project		Project	
UNIVERSITAT POLITÈCNICA DE VALÈNCIA		Analysis, diagnosis and redesign of an indexing table incorporated in a camshaft production line.	
ESCOLA TÈCNICA SUPERIOR ENGINYERIA INDUSTRIAL VALÈNCIA		Date	Scale
Author		15/04/2020	1:2
Initiated by Ernesto Colomer Torres (Ford employee). Developed and Completed by Llac Hernández Llinares (Author of the project).		Title	Sheet
		Hirth 360	9

SECTION H-H

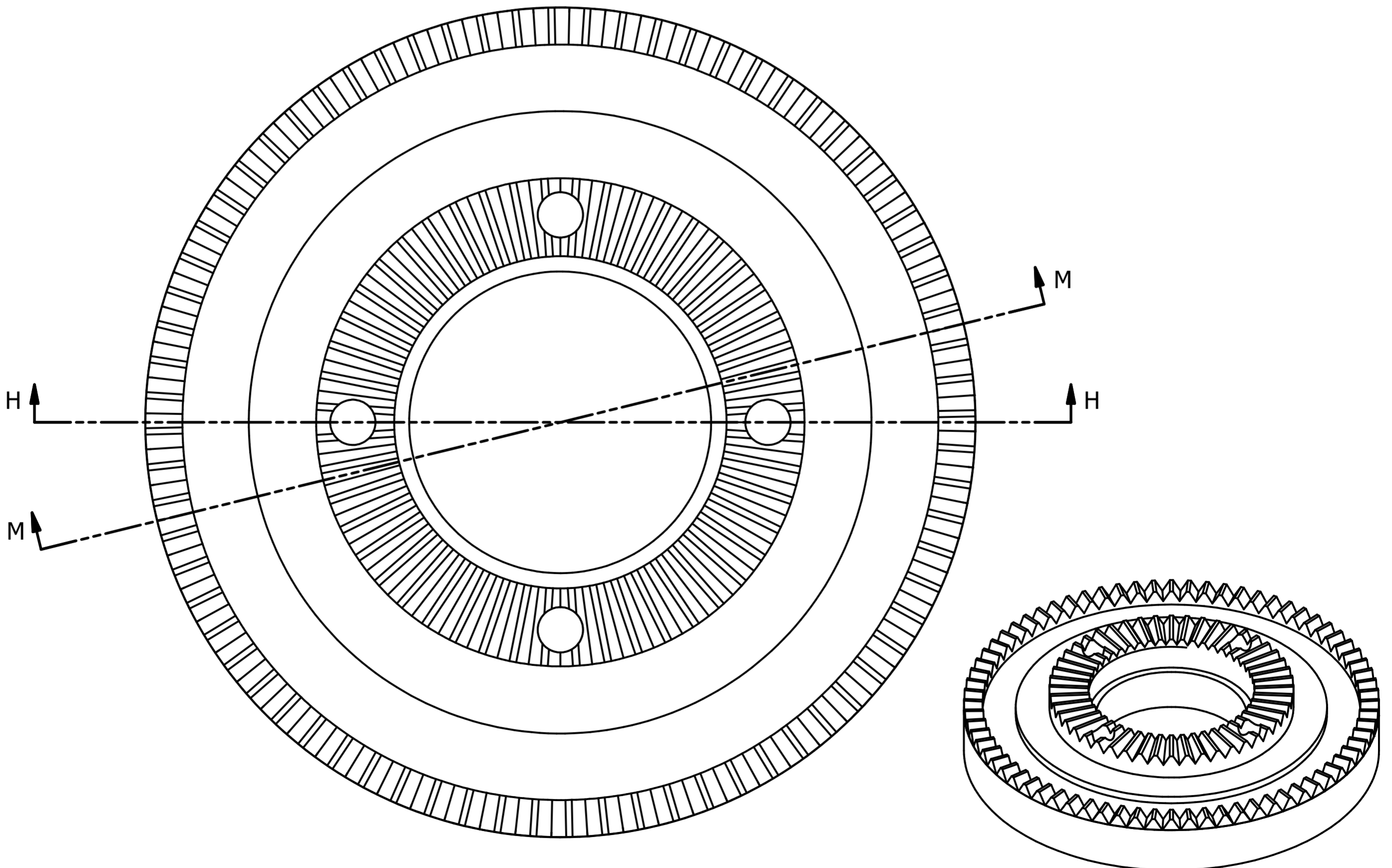


DETAIL J
SCALE 2 : 1



DETAIL E
SCALE 2 : 1

SECTION M-M

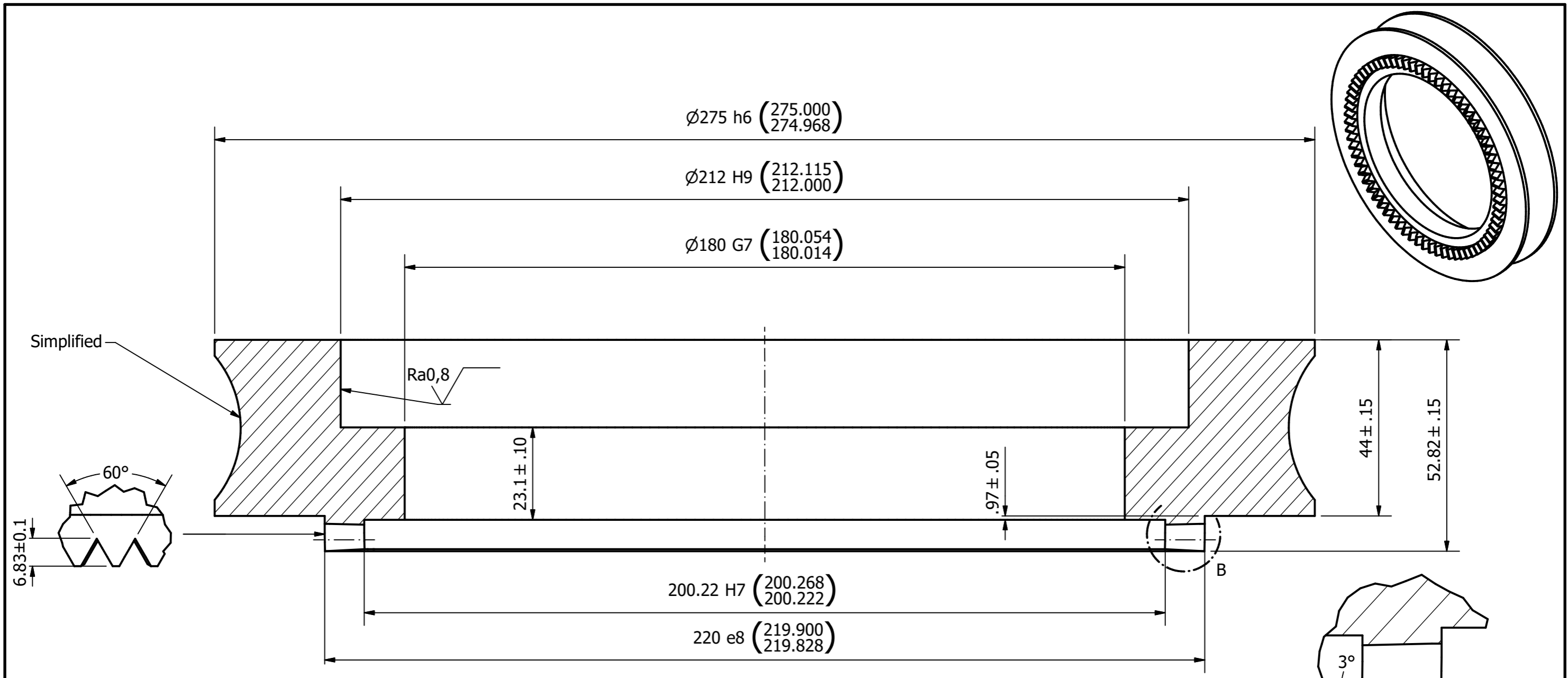


Material: Steel EN 1.7225- great resistance and good toughness.

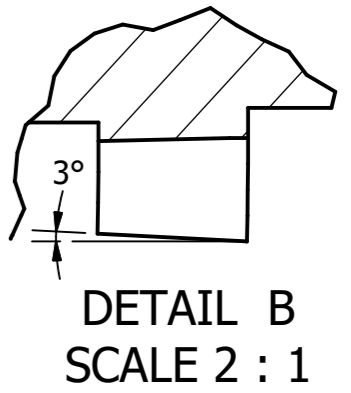
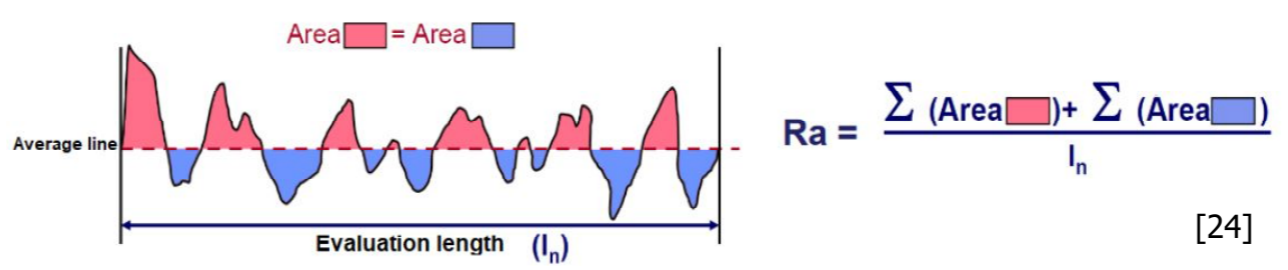
Tolerances according to ISO 2768 f

Linear dimensions	<6	>6-30	>30-120	>120-400	>400-1000	>1000-2000	>2000
Tolerances	±0,05	±0,1	±0,15	±0,2	±0,3	±0,5	

Industrial technologies engineering final project 		Project Analysis, diagnosis and redesign of an indexing table incorporated in a camshaft production line.	
Author Initiated by Ernesto Colomer Torres (Ford employee). Developed and Completed by Llac Hernández Llinares (Author of the project).		Date 15/04/2020	Scale 1:1
		Title Clutch	Sheet 11



Note: The shape of the crown gear has been simplified since it was not the issue of this project



**Material: Bronze EN1982
CC483K- high resistance and low speed applications.**

Tolerances according to ISO 2768 f							
Linear dimensions	<6	>6-30	>30-120	>120-400	>400-1000	>1000-2000	>2000
Tolerances	±0,05	±0,1	±0,15	±0,2	±0,3	±0,5	

Industrial technologies engineering final project 	Project	
	Analysis, diagnosis and redesign of an indexing table incorporated in a camshaft production line.	
Author	Date	Scale
	15/04/2020	1:1
Initiated by Ernesto Colomer Torres (Ford employee). Developed and Completed by Llac Hernández Llinares (Author of the project).	Title	Sheet
	Crown gear	12

Part 6

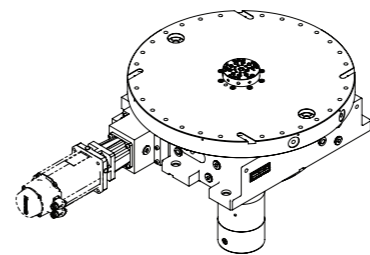
6 Annexes

This part of the document contains referenced information in point 1.2.2. that is related to the different indexing table types and the distribution of these components in the VEP. Ford employees at this factory provided both figures.

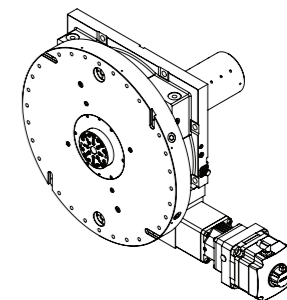
It also includes plans of the different bearings that have been used in this project, but as they are normalized components, we have not introduced them in the “plans” part. The introduction of these plans allows the comparison between bearings.

ETXE-TAR CNC MACHINES ROTARY TABLES IN FORD VEP

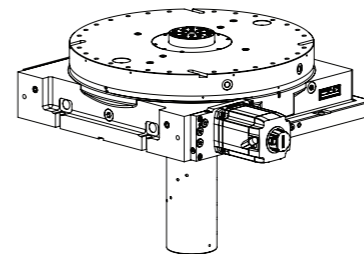
ETXE-TAR CNC MACHINES ROTARY TABLES IN FORD VEP									
PART	ET MACHINE NO.	Ejes	Platos	EQUIVALENCIA	OSCAR	OP	FIBRO REF	ET PO	SERIAL NO.
Camshaft	1175	1	1	A	60461958	12	4-166-973-0102	13/05998	0008120343-001
Camshaft	1411A	1	1	B	simbolizando	43C	4-616-928-0186	15/09178	0008128240-001
Camshaft	1411B	1	1	B	simbolizando	43D	4-616-928-0186	15/09178	0008128240-002
Crankshaft	1036	1	1	C	60461969	10	4-617-928-0077	11/07854	0008115797-005
Crankshaft	1037	1	1	C	60461969	50	4-617-928-0077	11/07854	0008115797-006
Crankshaft	1269	1	1	C	60461969	45	4-617-928-0077	14/04485	0008123245-001
Cylinder block	1194A	2	1	D	01586882 60444300	35A	4-645-928-0019	13/07630	0008120785-001
Cylinder block	1194B	2	1	D	01586882 60444300	35B	4-645-928-0019	13/07630	0008120785-002
Cylinder block	1039A	2	1	D	01586882 60444300	90A	4-645-928-0019	12/01005	0008116216-001
Cylinder block	1039B	2	1	D	01586882 60444300	90B	4-645-928-0019	12/01005	0008116216-002
Cylinder block	1377A	2	2	E	60751871	45A	4-664-928-0022	15/05514	0008126896-001
Cylinder block	1377B	2	2	E	60751871	45B	4-664-928-0022	15/05514	0008126896-003
Cylinder block	1378	2	2	E	60751871	93	4-664-928-0022	15/05514	0008126896-002
Cylinder block	1406	2	2	E	60751871	32	4-664-928-0022	16/00307	0008129311-001
Cylinder block	1407	1	2	F		38	4-197-973-0169	15/08746	0008128059-001
Cylinder head	1038A	2	1	D	01586882 60444300	35A	4-645-928-0019	16/00307	0008129311-002
Cylinder head	1038B	2	1	D	01586882 60444300	35B	4-645-928-0019	12/01005	0008116216-003
Cylinder head	1247	2	1	G		115	4-645-928-0021	14/00822	0008122147-001
Cylinder head	1272	2	1	D	01586882 60444300	35C	4-645-928-0019	14/07119	0008124073-001
Cylinder head	1427	2	1	D	01586882 60444300	35D	4-645-928-0019	15/04676	0008128311-002
Cylinder head	1487	2	2	E	60751871	25	4-664-928-0022	16/06193	0008129813-001
SPARE	N/A	2	1	D		N/A	4-645-928-0025	12/01005	0008116216-004
SPARE	N/A	2	2	E		N/A	4-664-928-0024	16/11515	TBD



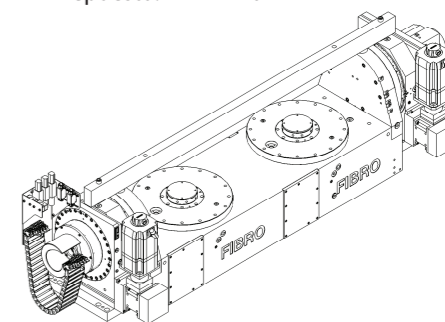
Ref. Mesa: 4-166-973-0102
 Lineas: Arbol de levas
 Operaciones: AL12
 Nº unidades: 1
 OSCAR: 60461958
 OSCAR Rep: -
 Equivalencia: -
 Repuesto: No



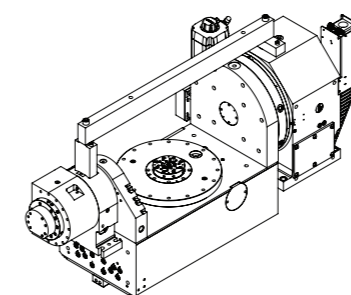
Ref. Mesa: 4-616-928-0186
 Lineas: Arbol de levas
 Operaciones: AL43 C (AL 43D)
 Nº unidades: 1 (2)
 OSCAR: simbolizando
 OSCAR Rep: -
 Equivalencia: -
 Repuesto: No



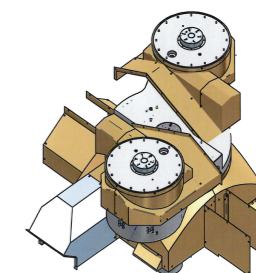
Ref. Mesa: 4-617-928-0077
 Lineas: Cigüeñales
 Operaciones: C10s, C45s, C50s
 Nº unidades: 3
 OSCAR: 60461969
 OSCAR Rep: -
 Equivalencia: -
 Repuesto: No



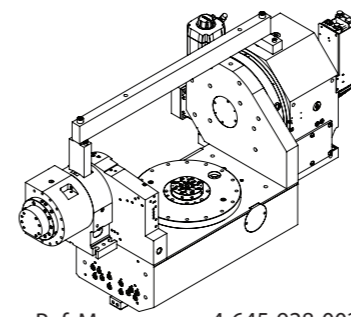
Ref. Mesa: 4-644-928-0022 (Grasa)
 Lineas: Bloques (y Culatas)
 Operaciones: BL32, BL45A, BL45B, BL93, (CU25)
 Nº unidades: 4 (5)
 OSCAR: 60751871
 OSCAR Rep: -
 Equivalencia: -
 Repuesto: No



Ref. Mesa: 4-645-928-0019 (Grasa)
 Lineas: Bloques (y Culatas)
 Operaciones: BL35A, BL35B, BL90A, BL90B, CU35A, CU35B, CU35C, CU35D,
 Nº unidades: 8
 OSCAR: 60444300
 OSCAR Rep: 01586882
 Equivalencia: 4-645-928-0025 (Aceite)
 Repuesto: Sí (1)

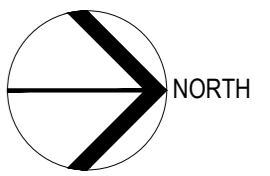
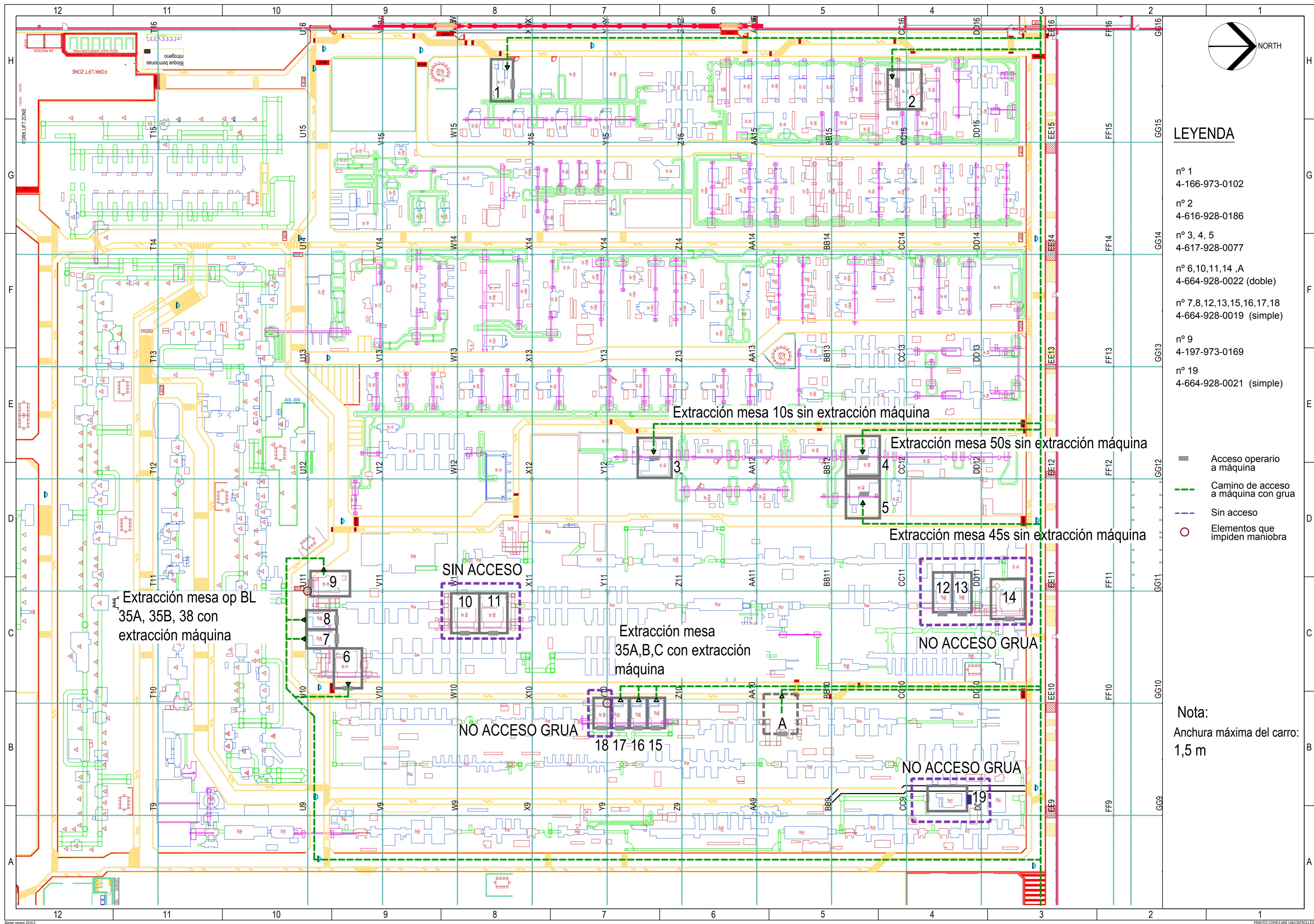


Ref. Mesa: 4-197-973-0169
 Lineas: Bloques
 Operaciones: BL38
 Nº unidades: 1
 OSCAR: -
 OSCAR Rep: -
 Equivalencia: -
 Repuesto: No



Ref. Mesa: 4-645-928-0021 (Grasa)
 Lineas: Culatas
 Operaciones: CU115
 Nº unidades: 1
 OSCAR: -
 OSCAR Rep: -
 Equivalencia: -
 Repuesto: No

TOTAL	
Nº modelos distintos:	7
Nº mesas simbolizadas:	5
Nº modelos con repuesto:	1
Nº unidades totales instaladas:	19 (21)



LEYENDA

- n° 1
4-166-973-0102
- n° 2
4-616-928-0186
- n° 3, 4, 5
4-617-928-0077
- n° 6,10,11,14 ,A
4-664-928-0022 (doble)
- n° 7,8,12,13,15,16,17,18
4-664-928-0019 (simple)
- n° 9
4-197-973-0169
- n° 19
4-664-928-0021 (simple)

- Acceso operario a máquina
- Camino de acceso a máquina con grua
- - Sin acceso
- Elementos que impiden maniobra

Nota:
Anchura máxima del carro:
1,5 m

Extracción mesa op BL
35A, 35B, 38 con
extracción máquina

SIN ACCESO

Extracción mesa
35A,B,C con extracción
máquina

NO ACCESO GRUA

Extracción mesa 10s sin extracción máquina

Extracción mesa 50s sin extracción máquina

Extracción mesa 45s sin extracción máquina

NO ACCESO GRUA

NO ACCESO GRUA

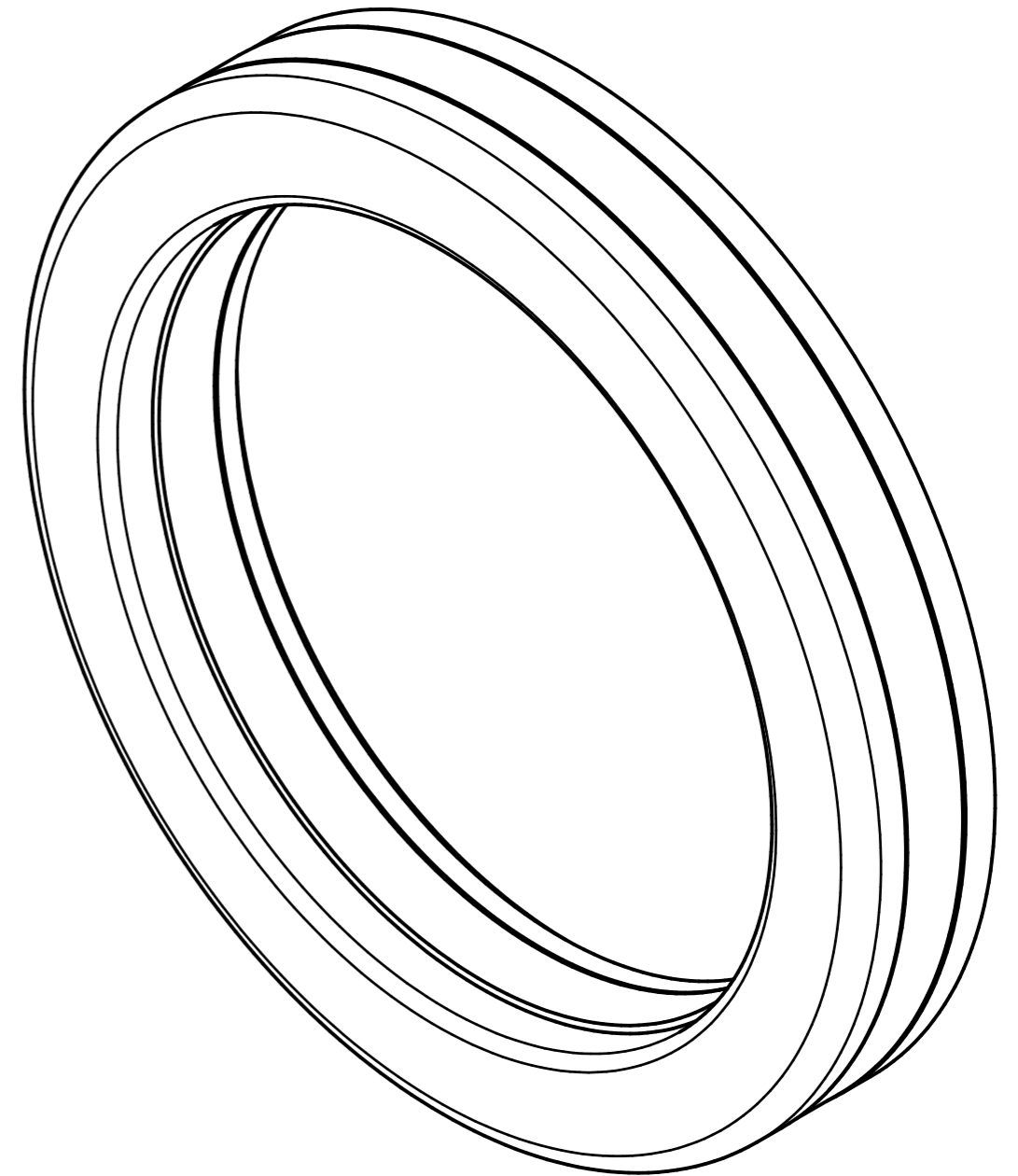
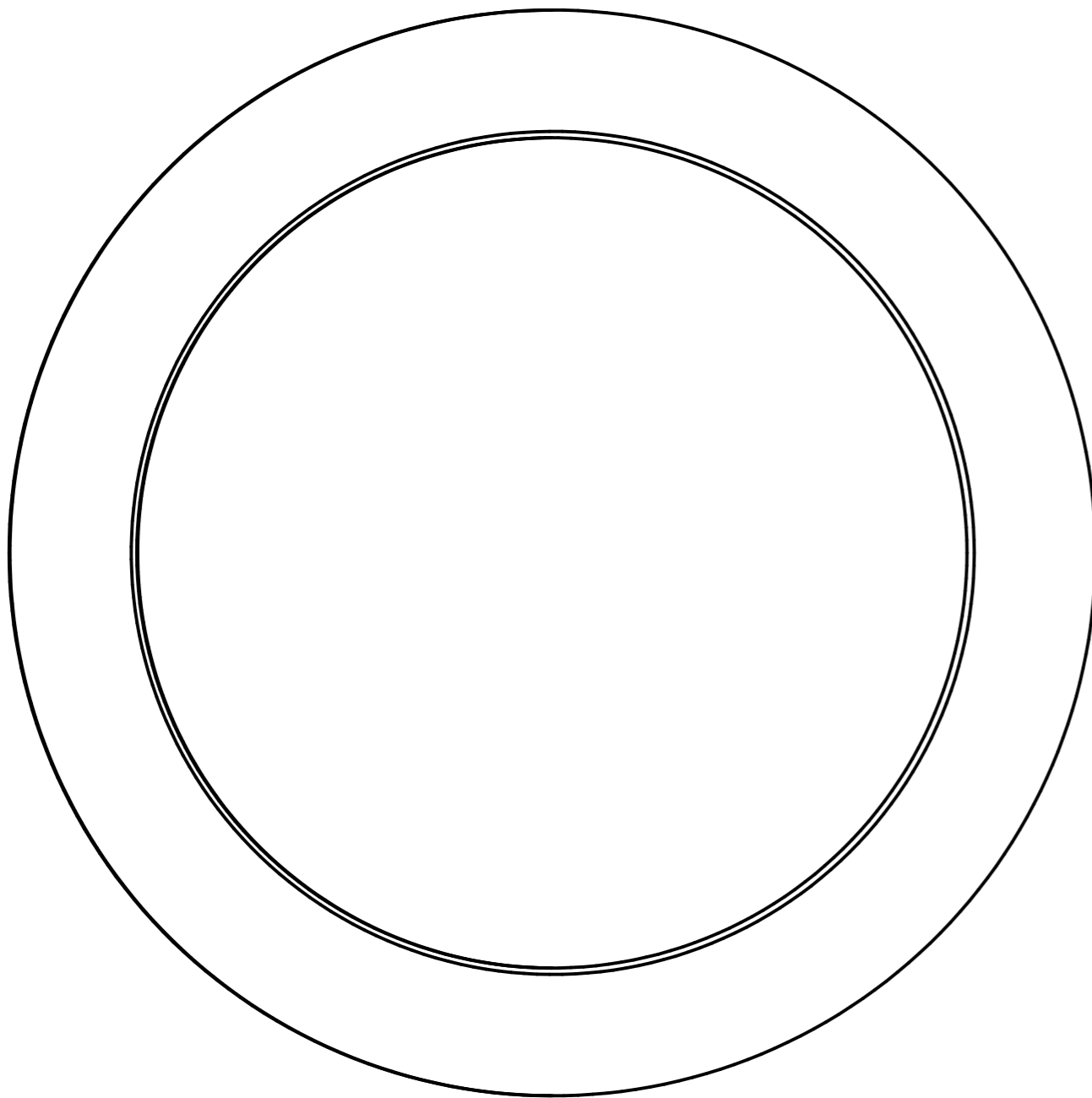
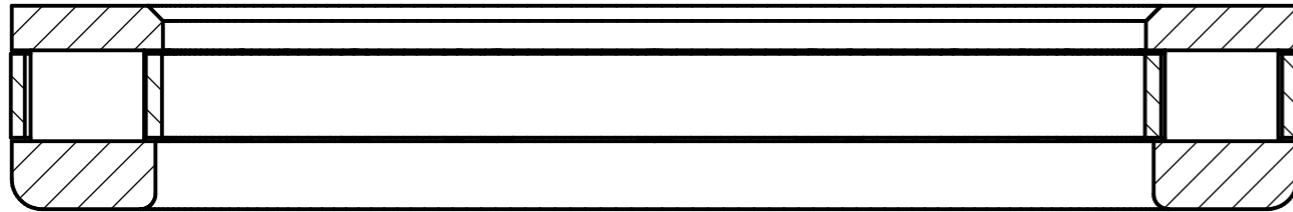
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Schaeffler references:

Rolling elements with cage: K81126.

Rolling surfaces: LS130170

Normalized component. Drawing
made from nominal measures.
Modified upper surface.



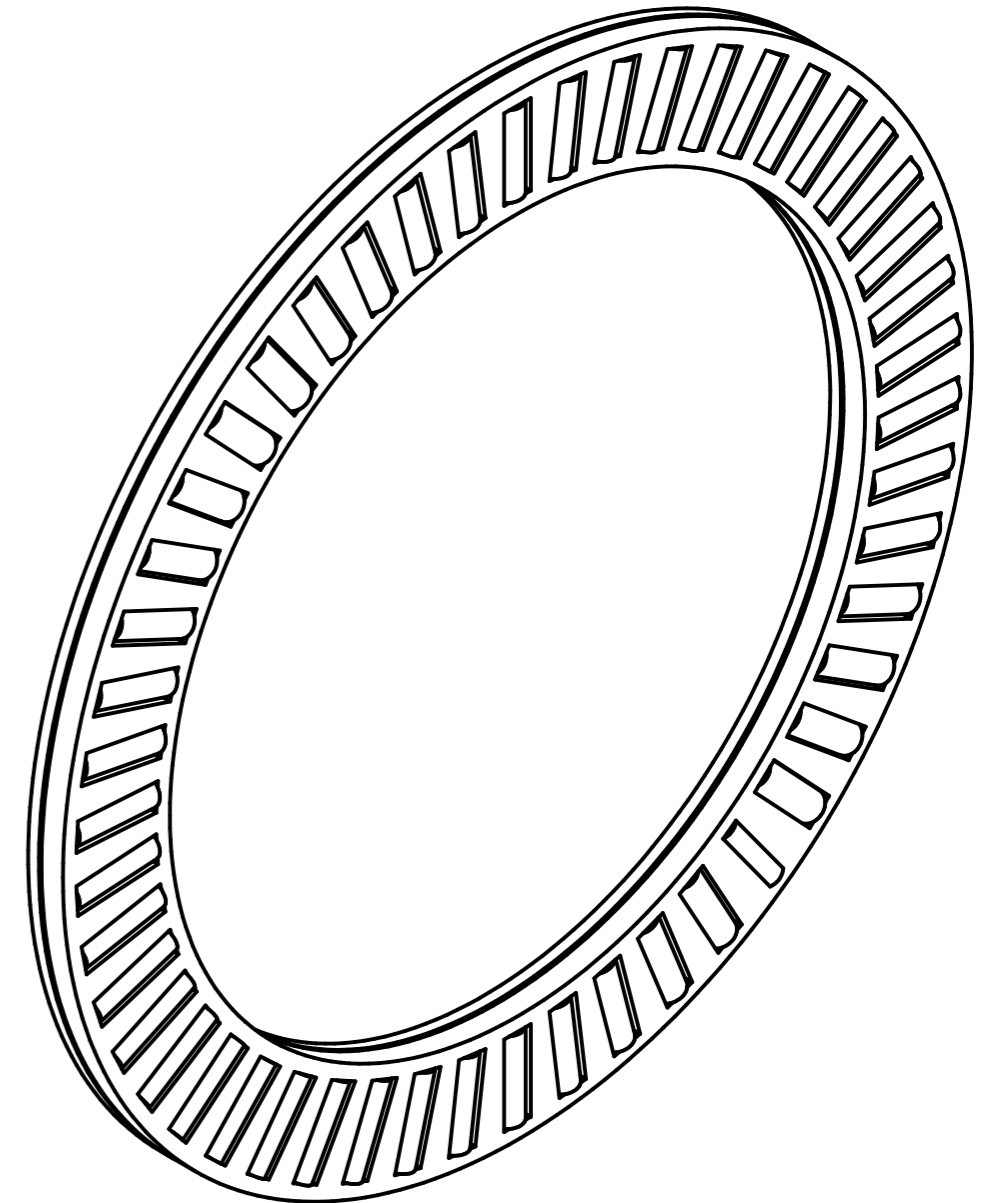
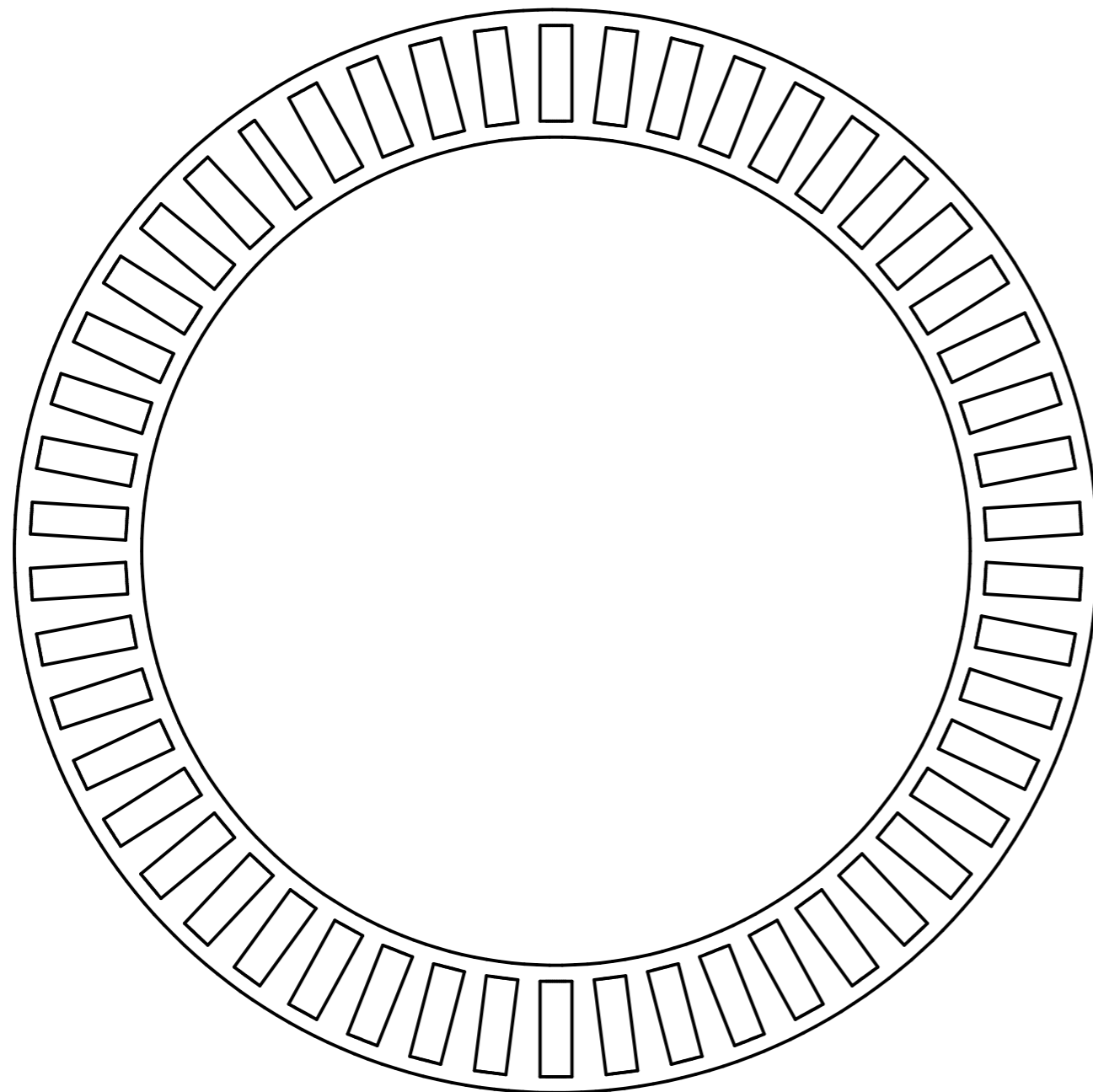
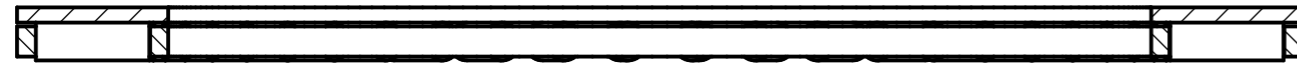
Industrial technologies engineering final project		Project	
 UNIVERSITAT POLITÈCNICA DE VALÈNCIA  ESCOLA TÈCNICA SUPERIOR ENGINYERIA INDUSTRIAL VALÈNCIA		Analysis, diagnosis and redesign of an indexing table incorporated in a camshaft production line.	
Author	Date	Scale	
Initiated by Ernesto Colomer Torres (Ford employee) Developed and completed by Llac Hernández Llinares	15/04/2020	1:1	
	Title	Sheet	
	Modified bearing	6	



Schaeffler references

Rolling elements with cage: AXK130170.

Rolling surface: AS130170.

Drawing represents original mounting of the bearing, with just the superior rolling surface mounted.



Industrial technologies engineering final project		Project	
 UNIVERSITAT POLITÈCNICA DE VALÈNCIA  ESCOLA TÈCNICA SUPERIOR ENGINYERIA INDUSTRIAL VALÈNCIA		Analysis, diagnosis and redesign of an indexing table incorporated in a camshaft production line.	
Author	Initiated by Ernesto Colomer Torres (Ford employee) Developed and completed by Llac Hernández Llinares	Date	Scale
		15/04/2020	1:1
		Title	Sheet
		Original bearing	6.1

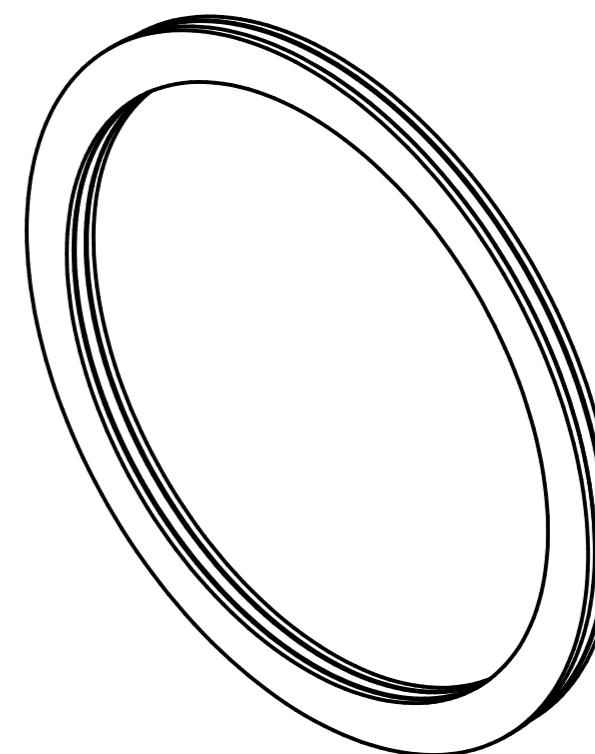
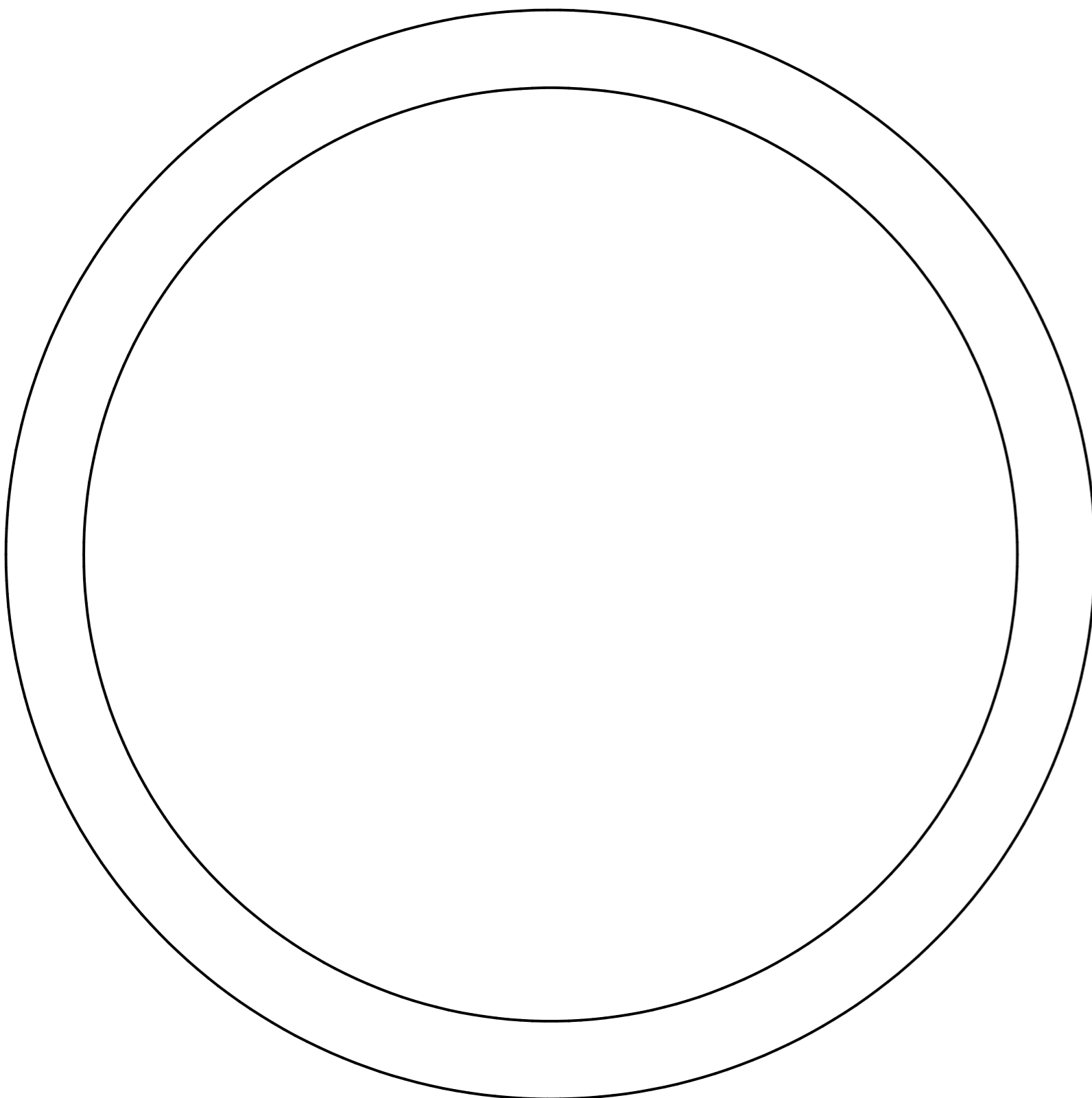
Schaeffler references



Rolling elements with cage: AXK180210.

Rolling surfaces: AS180210.



Normalized component. Drawing made from nominal measures. This component is used before and after the indexing table modifications.



Industrial technologies engineering final project		Project	
 UNIVERSITAT POLITÈCNICA DE VALÈNCIA  ESCOLA TÈCNICA SUPERIOR ENGINYERIA INDUSTRIAL VALÈNCIA		Analysis, diagnosis and redesign of an indexing table incorporated in a camshaft production line.	
Author	Date	Scale	
Initiated by Ernesto Colomer Torres (Ford employee) Developed and completed by Llac Hernández Llinares	15/04/2020	1:1	
	Title	Sheet	
	Crown gear bearing	7	

